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NAVIGATION

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NAVIGATION

FOR STUDENTS OR MARINERS PREPARING TO TAKE EXAMINATIONS FOR OFFICER'S LICENSES

BY

GEORGE L. HOSMER

Professor of Geodesy, Massachusetts Institute of Technology

SECOND EDITION

REWRITTEN AND ENLARGED

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PREFACE TO THE SECOND EDITION

THE adoption of Civil Time in the Nautical Almanac in place of Astronomical Time has made it necessary to re-write a large part of this book. In addition to the changes in all astronomical calculations necessitated by this change of time the matter of compass deviations and compass adjustment is treated more fully; methods that are now considered obsolete have been dropped; and the latest tables for laying down position lines are described. Several minor improvements have been made and many cuts added.

G. L. H.

CAMBRIDGE, *March*, 1925.

PREFACE TO THE FIRST EDITION

This book is written as an aid for those who wish to study navigation with the intention of taking examinations to obtain officer's licenses. It is assumed that the reader may not have a knowledge of mathematics beyond that of simple arithmetic. No theory or algebraic formulas have been introduced in the body of the book, but only the simple working rules required for the daily routine of the navigator. The author has endeavored to present the subject in a clear and simple manner, yet without omitting anything essential. The methods, of computation have been illustrated by numerous examples, and many problems have been left for the student to solve.

No attempt has been made to treat all the subjects in which a candidate will be examined (such as seamanship, rules of the road, etc.), but it was thought advisable to include certain useful information at the end of the book, for convenience of reference.

The value of such a book must depend largely upon the reliability of the statements and the accuracy of the computations. The author will consider it a favor if his attention is called to any errors that may be discovered, so that they may be corrected as opportunity offers.

The author wishes to acknowledge his indebtedness to Professors C. B. Breed and J. W. Howard of the Massachusetts Institute of Technology and to Mr. Rudolph Beaver for valuable suggestions and criticism of the manuscript.

G. L. H.

Cambridge, *December*, 1917.

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NAVIGATION

CHAPTER I

INSTRUMENTS USED IN NAVIGATION

The Log, Lead, and Sounding Machine

THE subject of navigation is usually divided into two parts, (1) that of obtaining the position of the vessel at any time by keeping account of the directions and distances sailed from some known point, called navigation by dead reckoning; and (2) that of finding the position by observation of celestial bodies, called navigation by observation.

The principal instruments used for navigation by dead reckoning are the log, the compass, and the lead; the pelorus, chart, protractor, parallel rulers, and dividers are also used. The instruments used for navigation by observation are the sextant, the chronometer, pelorus and azimuth sights for the compass, or the shadow pin.

THE LOG

Distances are obtained by measuring the movement of the vessel with reference to the water so as to obtain either the total distance or the speed. This is done either by means of the log or by reading the number of revolutions of the engine. The *chip log*, formerly much used on sailing vessels, consists of a light piece of board weighted on one edge so as to float in an upright position when thrown into the water (Fig. 1*a*). The line attached to the log is divided into lengths called *knots*, beginning 15 or 20 fathoms from the chip, at a point marked by a piece of red bunting. Each of these distances is marked by means of pieces of fish line run through the log line, one for the first, two for the second, etc., each one representing a nautical mile or *knot*. Every two tenths of a knot is marked by a piece of white rag. The log was generally used in connection with a sand glass, and the distances between marks on the log line must be figured such that the length of a knot on the line has the same relation to the sea mile (6080 ft.) that the time of the sand glass has to one hour, or, expressed as a proportion, for a 28^s glass,

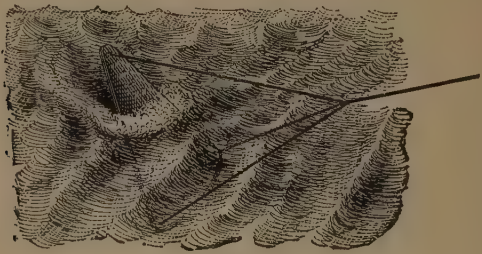


FIG. 1*a*. Chip Log.

$$x : 6080 :: 28 : 3600$$

from which

$$x = 47.29 \text{ ft.}$$
$$= 47 \text{ ft. } 3\tfrac{1}{2} \text{ ins.}$$

Therefore the knots on the log line must be spaced 47 ft. $3\frac{1}{2}$ ins. apart.

When the log is hove the sand glass is started just as the red bunting passes out. When the sand has all run out the observer notes the number of knots and tenths which have passed out. Since the log has not moved through the water this number of knots must be the number of nautical miles (or knots) per hour that the vessel has sailed with reference to the water. If the line is now given a sudden jerk it will free a wooden peg, fastened to two of the lines, so that the chip will lie flat on the water and can be easily hauled aboard.

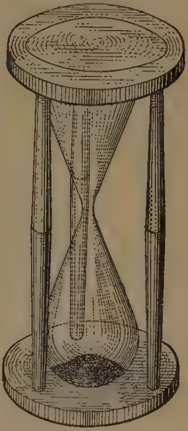


FIG. 1*b*. Sand Glass.

The *patent log*, or taffrail log, Fig. 2, is the one generally used at the present time; it consists of a rotator, similar to the propeller of a power boat, attached to a stout line. When this is thrown into the water it is set rotating, the twist being carried by the log line to the wheels of a recording mechanism which is fastened to the rail. The hand of a dial shows the number of miles actually traveled. The dial is read at the beginning and end of each course run and at any other time when the position of the ship is desired. The distances are found by taking the differences between readings of the dial. If the hand has passed the hundred mark between readings it is necessary to add 100 to the second reading before making the subtraction.

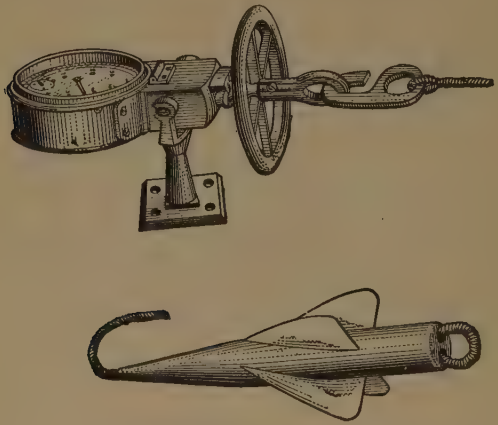


Fig. 2. Patent Log.

A new log should always be tested by running over some known distance. If it shows an error the correction per mile should be found and this should be applied to all distances taken with this log.

On steam vessels the distance run may be found very accurately by means of the revolutions of the propeller, after a few runs have been made so that the relation between the number of revolutions and the actual distance becomes known. A careful record of the runs should be kept under varying conditions of weather, tide, etc., so that the proper speed may be estimated. It is well not to trust entirely to either of these but to take into account both the log and the revolutions in estimating the distance.

THE LEAD LINE

Depths of water (soundings) are measured by means of a lead weight attached to a marked line. The hand lead, weighing about 7 to 14 lbs., is used for measuring depths of about 20 fathoms or less.* The line is marked as follows:

2 fathoms, 2 strips of leather
3 fathoms, 3 strips of leather
5 fathoms, a white rag
7 fathoms, a red rag
10 fathoms, a piece of leather with a hole in it
13 fathoms, same as at 3
15 fathoms, same as at 5
17 fathoms, same as at 7
20 fathoms, with 2 knots
25 fathoms, with 1 knot
30 fathoms, with 3 knots

The marked fathoms are called *marks;* the unmarked fathoms are called *deeps.* Half and quarter fathoms are estimated.

---

* The fathom, a length of 6 feet, is the ordinary unit for measuring depths.

The bottom of the lead is hollowed out so that the depression can be filled with tallow for obtaining samples of the bottom. This is called "arming" the lead.

THE SOUNDING MACHINE

For deep-sea sounding the best instrument is the "deep-sea sounding machine," the Thompson machine being probably the most widely known. This consists of a heavy lead to which is attached a cylindrical case containing a glass tube arranged so as to measure depths by means of the pressure exerted by the water. The pressure forces water into the tube and the height of the water is indicated by discoloration of a chemical placed in the tube. A scale accompanies the instrument for measuring the fathoms directly. The machine is lowered by means of fine piano wire running off a reel. In using this machine it is not necessary to stop the vessel, or even to slow down, because the machine registers the depth regardless of the length of wire that is out.

In later forms of this instrument a ground glass tube has been substituted for the chemically coated tube. That part of the ground glass which is wet will show clear, so that a reading can be obtained. If the tube is thoroughly dried it can be used again and again, a great advantage over the chemical tube.

SONIC DEPTH FINDER

If a vessel is equipped with the necessary apparatus the depth may be measured by means of sound waves. For shallow depths the instrument measures the angle at which the sound sent out from a certain point on the ship is reflected back from the bottom to another point on the ship. For greater depths the instrument measures the time required for the sound to travel from the ship to the bottom and back again. In either case the depth is determined at once. The apparatus is simple to operate and its use may be easily learned.

Soundings shown on the chart are usually the depths below "mean low water." They may be in feet or in fathoms, according to the legend on the chart. When navigating in shoal water it will be necessary to allow for the height of tide to obtain the actual depth at the time.

PROBLEM

What would be the length of the knot on a log line to be used with a 14^s glass?

Ans. 23 ft. 8 ins.

CHAPTER II

THE COMPASS

The mariner's compass consists of a magnetic needle, or a group of needles, to which is attached a circular card marked with the *points* or the degrees to show the course steered. The magnet and card are suspended on a pivot in a bowl and covered with a glass; the best compasses have the bowl filled with a liquid to steady the needle and to diminish the pressure on the pivot. The directive force of the earth's magnetism causes the magnetized needle to take a north-and-south direction; hence the compass shows the direction of north and also shows the direction in which the vessel is headed. We may imagine the surface of the earth to have drawn upon it meridian lines, or north-and-south lines, extending from the north pole to the south pole, like those shown on charts or on globes. The angle at which the ship crosses any meridian line is called her *course* and is shown by the ship's compass (Fig. 3). The number of degrees in this angle is the same as the number of degrees on the compass card and is also the same as the number of degrees on an arc of the horizon between the meridian and the line of the keel. If the compass had no error whatever the north-and-south line of the compass card would have the same direction as the earth's meridian and the compass would then show at once the true course of the vessel. As a matter of fact in a correct compass the needle points to the magnetic north and the course shown is the magnetic course, and this is usually different from the true course. If the compass is affected by iron or steel, such as the hull of the vessel or iron cargo, the compass will not even show a correct magnetic course.

The **true** course is the angle the ship's keel makes with the true (geographical) meridian. The **magnetic** course is the angle made by the keel with the magnetic meridian. The **compass** course is the angle made by the keel with the compass needle itself; this will differ from the magnetic course if the compass is affected by iron. The **compass course** is the one you **steer.** The **true course** is the one you get when you observe the **sun,** or when you take a course from the **true meridians** of a chart.

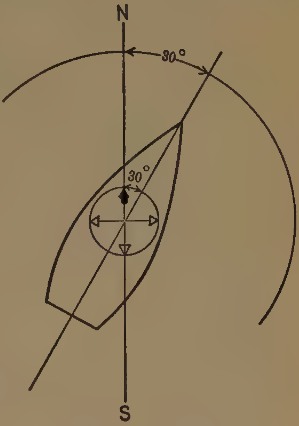


FIG. 3. The Course.

Compasses are marked in three different ways. When the "points" of the compass are used the circumference of the card is first divided into four quadrants by marking the cardinal points, N, E, S, W; then these quadrants are each divided into halves by the intercardinal points NE, SE, SW, NW. These spaces are again subdivided by adding the NNE, ENE, ESE, etc., points. Halfway

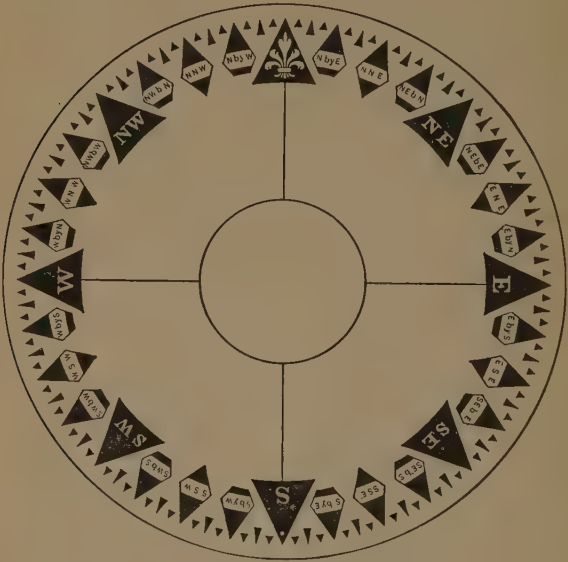


FIG. 4. The Points of the Compass.

between these points are placed the points marked N by E, NE by N, NE by E, E by N, etc., giving in all 32 points of the compass. In order to show courses still more accurately the spaces between the whole points are divided into quarters; these are read N $\frac{1}{4}$ E, N $\frac{1}{2}$ E, N $\frac{3}{4}$ E, etc. (Fig. 4). The points and quarter points are given in their order in the following table, together with the angle in degrees, minutes and seconds which they make with the meridian. Since there are always just 360° in the circumference of a circle the "point" equals $360° \div 32$, or $11° 15'$. The quarter point equals one fourth of $11° 15' = 2° 48' 45''$, or nearly 3°. This is accurate enough for steering sailing vessels. For steam navigation smaller divisions are needed.

Notice that when reading the quarter points we always proceed from the N toward the E or W, or from the S toward the E or W, except when counting from the E or W point or from an intercardinal point, in which case we count back toward the meridian for one point. For example, we may say E $\frac{1}{2}$ N, not E by N $\frac{1}{2}$ E; or, NE $\frac{1}{4}$ N, not NE by N $\frac{3}{4}$ E. This is the practice followed in the United States Navy.

In some localities, however, it is the custom to count from the intercardinal points each way for two points. For example, they would say NE by N $\frac{1}{2}$ N instead of NNE $\frac{1}{2}$ E, as given here.

In order to divide the circumference a little finer and also to use a division which is more convenient for calculation the card is divided into 360 degrees. These degrees were formerly marked by having each of the four quadrants divided into 90 degrees, starting from the N and S points as 0°, the 90° points being at the E and W (Fig. 5). When this system is used a course is shown by writing first the N or S point, whichever is nearer, then

	Points	Angular measure		Points	Angular measure
North to east		° ′ ″	East to south		° ′ ″
North...........	0	0 00 00	East...........	8	90 00 00
N ¼ E..........	¼	2 48 45	E ¼ S..........	8¼	92 48 45
N ½ E..........	½	5 37 30	E ½ S..........	8½	95 57 30
N ¾ E..........	¾	8 26 15	E ¾ S..........	8¾	98 26 15
N by E..........	1	11 15 00	E by S..........	9	101 15 00
N by E ¼ E....	1¼	14 03 45	ESE ¾ E......	9¼	104 03 45
N by E ½ E....	1½	16 52 30	ESE ½ E......	9½	106 52 30
N by E ¾ E....	1¾	19 41 15	ESE ¼ E......	9¾	109 41 15
NNE............	2	22 30 00	ESE............	10	112 30 00
NNE ¼ E......	2¼	25 18 45	SE by E ¾ E..	10¼	115 18 45
NNE ½ E......	2½	28 07 30	SE by E ½ E..	10½	118 07 30
NNE ¾ E......	2¾	30 56 15	SE by E ¼ E..	10¾	120 56 15
NE by N........	3	33 45 00	SE by E........	11	123 45 00
NE ¾ N........	3¼	36 33 45	SE ¾ E........	11¼	126 33 45
NE ½ N........	3½	39 22 30	SE ½ E........	11½	129 22 30
NE ¼ N........	3¾	42 11 15	SE ¼ E........	11¾	132 11 15
NE..............	4	45 00 00	SE..............	12	135 00 00
NE ¼ E........	4¼	47 48 45	SE ¼ S........	12¼	137 48 45
NE ½ E........	4½	50 37 30	SE ½ S........	12½	140 37 30
NE ¾ E........	4¾	53 26 15	SE ¾ S........	12¾	143 26 15
NE by E........	5	56 15 00	SE by S........	13	146 15 00
NE by E ¼ E...	5¼	59 03 45	SSE ¾ E.......	13¼	149 03 45
NE by E ½ E...	5½	61 52 30	SSE ½ E.......	13½	151 52 30
NE by E ¾ E...	5¾	64 41 15	SSE ¼ E.......	13¾	154 41 15
ENE............	6	67 30 00	SSE............	14	157 30 00
ENE ¼ E.......	6¼	70 18 45	S by E ¾ E....	14¼	160 18 45
ENE ½ E.......	6½	73 07 30	S by E ½ E....	14½	163 07 30
ENE ¾ E.......	6¾	75 56 15	S by E ¼ E....	14¾	165 56 15
E by N..........	7	78 45 00	S by E..........	15	168 45 00
E ¾ N..........	7¼	81 33 45	S ¾ E..........	15¼	171 33 45
E ½ N..........	7½	84 22 30	S ½ E..........	15½	174 22 30
E ¼ N..........	7¾	87 11 15	S ¼ E..........	15¾	177 11 15

	Points	Angular measure		Points	Angular measure
South to west		° ′ ″	West to north		° ′ ″
South	16	180 00 00	West	24	270 00 00
S ¼ W	16¼	182 48 45	W ¼ N	24¼	272 48 45
S ½ W	16½	185 37 30	W ½ N	24½	275 37 30
S ¾ W	16¾	188 26 15	W ¾ N	24¾	278 26 15
S by W	17	191 15 00	W by N	25	281 15 00
S by W ¼ W	17¼	194 03 45	WNW ¾ W	25¼	284 03 45
S by W ½ W	17½	196 52 30	WNW ½ W	25½	286 52 30
S by W ¾ W	17¾	199 41 15	WNW ¼ W	25¾	289 41 15
SSW	18	202 30 00	WNW	26	292 30 00
SSW ¼ W	18¼	205 18 45	NW by W ¾ W.	26¼	295 18 45
SSW ½ W	18½	208 07 30	NW by W ½ W.	26½	298 07 30
SSW ¾ W	18¾	210 56 15	NW by W ¼ W.	26¾	300 56 15
SW by S	19	213 45 00	NW by W	27	303 45 00
SW ¾ S	19¼	216 33 45	NW ¾ W	27¼	306 33 45
SW ½ S	19½	219 22 30	NW ½ W	27½	309 22 30
SW ¼ S	19¾	222 11 15	NW ¼ W	27¾	311 11 15
SW	20	225 00 00	NW	28	315 00 00
SW ¼ W	20¼	227 48 45	NW ¼ N	28¼	317 48 45
SW ½ W	20½	230 37 30	NW ½ N	28½	320 37 30
SW ¾ W	20¾	233 26 15	NW ¾ N	28¾	323 26 15
SW by W	21	236 15 00	NW by N	29	326 15 00
SW by W ¼ W	21¼	239 03 45	NNW ¾ W	29¼	329 03 45
SW by W ½ W	21½	241 52 40	NNW ½ W	29½	331 52 30
SW by W ¾ W	21¾	244 41 15	NNW ¼ W	29¾	334 41 15
WSW	22	247 30 00	NNW	30	337 30 00
WSW ¼ W	22¼	250 18 45	N by W ¾ W	30¼	340 18 45
WSW ½ W	22½	253 07 30	N by W ½ W	30½	343 07 30
WSW ¾ W	22¾	255 56 15	N by W ¼ W	30¾	345 56 15
W by S	23	258 45 00	N by W	31	348 45 00
W ¾ S	23¼	261 33 45	N ¾ W	31¼	351 33 45
W ½ S	23½	264 22 30	N ½ W	31½	354 22 30
W ¼ S	23¾	267 11 15	N ¼ W	31¾	357 11 15
			North	32	360 00 00

the number of degrees, then the E or W, according to which way the degrees are counted. For example,

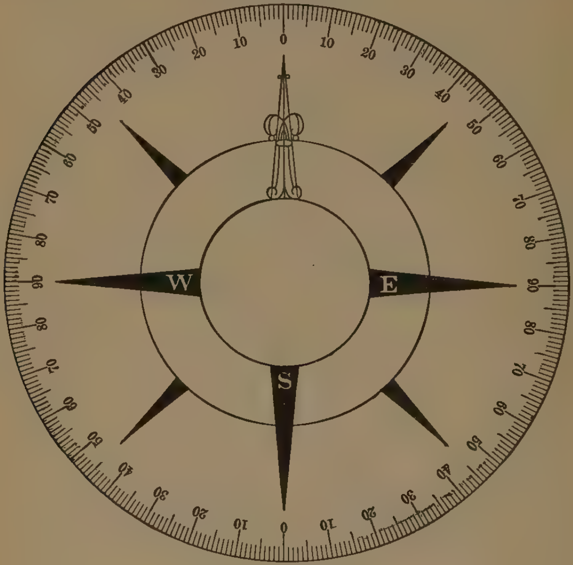


Fig. 5. The Quadrants.

S 30° E, N 65° W. Courses are not ordinarily reckoned beyond 90° in this system.

A third way of dividing the circumference, which is coming into general use, is to number the degrees, starting from 0° at the N point, right-handed (with the sun) up to 360° (Fig. 6). Directions expressed in this system are sometimes called azimuths. It is not necessary to use any letters in naming a course in this system. A course of 90° is E, 180° is S, 270° is W, and 360° is N.

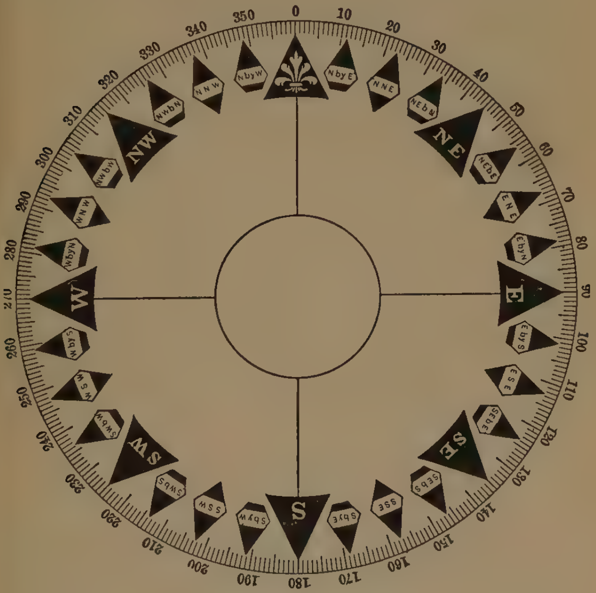


FIG. 6. The 360° System.

The navigator should make himself familiar with this system because it has decided advantages over the others. The following comparison will show the relation existing among the three different systems.

Points		Quadrants		Azimuths
NE	=	N 45° E	=	45°
SE	=	S 45° E	=	135°
SW	=	S 45° W	=	225°
NW	=	N 45° W	=	315°

BOXING THE COMPASS

Although the degrees are much used, the points will be found marked on nearly all compasses, and the navigator should be perfectly familiar with them and be able to repeat the names of the 32 points in proper order, either way, around the compass. This is called "boxing the compass."

LUBBER LINE

On the inside of the bowl of the compass is a line set parallel to the keel of the vessel, called the *lubber line.* The point of the compass or the number of the degree which is opposite this line is the compass course on which the ship is then headed.

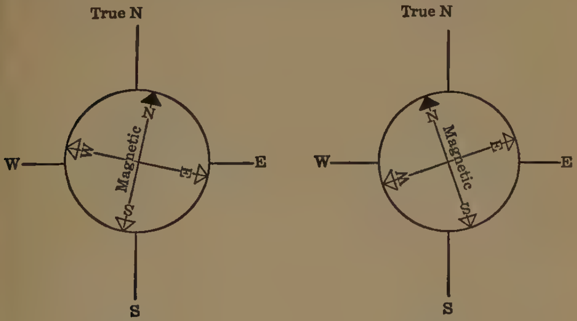
CIRCLES — ANGLES — DEGREES

In order to understand bearings, courses, etc., the student should understand angles and their measurement in degrees, minutes and seconds.

For an explanation of these terms see Chapter III, p. 50.

VARIATION

Except at a very few places on the earth the compass does not point to the true north. Furthermore, it does not continue to point in exactly the same direction at any place but changes slowly from year to year. The difference between the direction of the magnetic north and the true, or geographical, north is called the *variation*. In other words it is the angle between the magnetic meridian and the true meridian. The variation is called *East* if the north end of the compass is drawn to the right, or east, of the true north; it is *West* if the north end of the compass is drawn to the left, or west, of true north. It may help you to remember which way the compass is turned at any place if you notice that the magnetic N pole is situated to the north of Hudson Bay (lat. 70° N. long. 97° W) about 1200 miles from the true pole through which all the true meridians pass. The compass points nearly (but not exactly) toward this magnetic pole. In the middle of the North Atlantic



Variation
1 point East.

Variation
20° West.

FIG. 7.

Ocean the compass points about 20° to 25° west of true north. In the middle of the North Pacific Ocean it points about 10° east of true north.

Along a certain line, passing through Brazil, Venezuela, Haiti and South Carolina, the compass points to true north, and for places on this line there is no variation. This is called the *Agonic line*, or *line of no variation.* There is also another line of no variation passing through Australia, Sumatra, British India, Arabia and the Black Sea.

The amount of variation in any part of the world at any time will be found on the sailing charts, the pilot charts, or on the Variation chart. It is shown by means of lines drawn for every 1° (sometimes for every 5°) of variation. These lines are all numbered with the degrees of the variation. The *annual change* in the variation is shown either by another series of lines marked with the number of minutes of annual change, or by the number of minutes printed in figures on the chart. By means of this annual change the variation on the chart may be corrected to get the variation for a later year.

The variation is also given on the Coast or Harbor charts, but in this case it is usually shown by means of a *compass rose* printed on the chart and turned through the proper angle to show the variation at that place. The amount of annual change in the variation is stated on the chart. (See Chart, p. 62).

The variation is generally so large that it is impossible to set a course accurately without making due allowance for this error, so it is very important that the navigator should know all about its effect on his compass and how to allow for it.

NAMING THE VARIATION

If the N point of the compass is to the **East** (right) of true North the variation is called **East.** If it is **West** (left) of true North the variation is called **West** (Fig. 7).

CORRECTING A MAGNETIC COURSE FOR VARIATION

If the variation is **East,** as in Fig. 8, all **true** courses are to the **right** of the corresponding magnetic courses. For example, if the N end of the compass needle is one point to the East (right), the true course, E by S, is in the same direction as the magnetic course East, that is, the true course is found to the right of the magnetic course (on the card) as you look from the center of the compass along the course. This is true of every course so long as the variation is one point East.* Therefore we have the following rule:

> **To correct a magnetic course for variation, apply the amount of variation to the right when the variation is East; to the left if it is West.**

The above rule is true for every course all the way round the compass. Suppose that the variation is 2 points East and let us see how it will work out on the four different headings of the ship shown in Fig. 9. The ship is first headed N by compass, and we see that that

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* Hold the end of a string at the center of Fig. 8 and draw the string taut in any direction. The magnetic direction is on the inside compass and the true direction is on the outside compass; the true direction is always one point farther to the right.

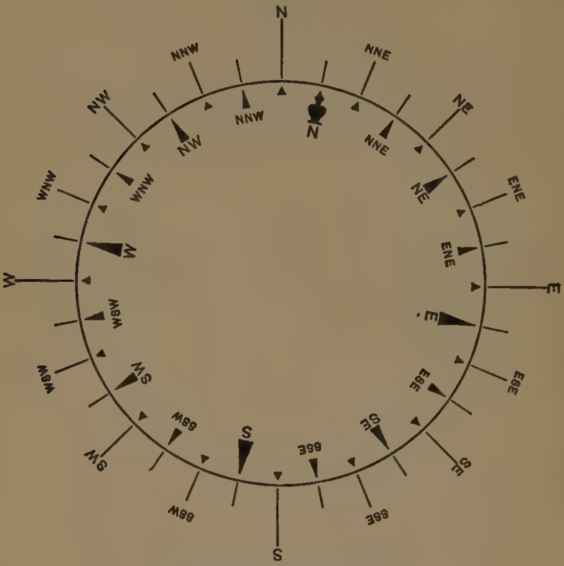


FIG. 8. Variation 1 Point East.

is really NNE (true), or 2 points to the right. In the second diagram she is headed East magnetic, but ESE true, or 2 points to the right. The other two diagrams show the same result.

The above general rule holds true, no matter how the course may be indicated. If the course is shown by the degrees of the quadrant, as N 30° E, N 30° W, the varia-

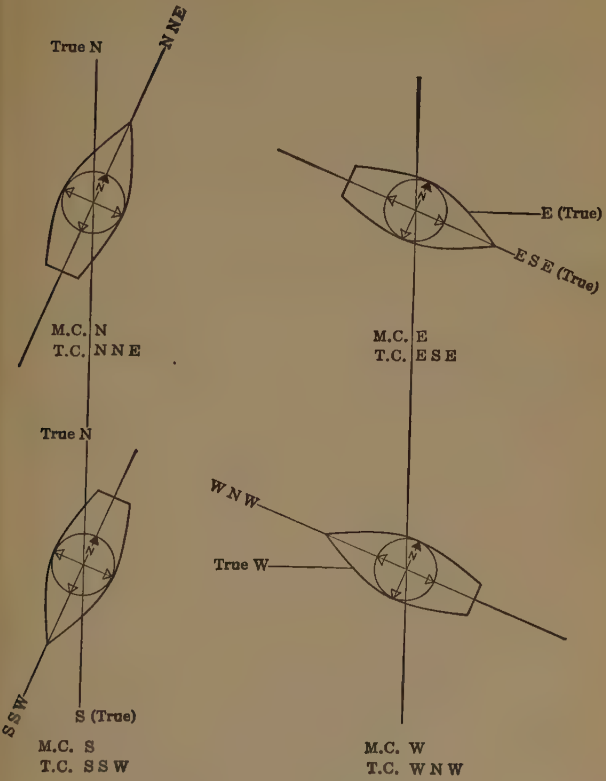
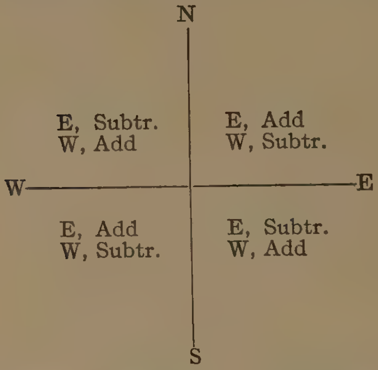


FIG. 9. Variation 2 Points East.

tion will have to be added or subtracted according to which quadrant the course is in. If the magnetic course is either in the NE or the SW quadrants and the variation is E the true course is found by adding the variation. If the magnetic course is either in the NW or the SE quadrants the true course is found by subtracting the E variation. For W variation the opposite is the case. This rule for the four quadrants may be remembered by means of the following diagram.



If the compass is divided into degrees and numbered from the N point right-handed to 360° the manner of making the correction is much simpler. In this case when going to the right you *always* add. That is, if the variation is East the true course is found by adding the variation, no matter which quadrant the course is in. If the variation is West the true course is obtained by subtracting the variation from the magnetic course. (If the variation is larger than the course add 360° to the course before subtracting). With this compass the rule is easier to remember and there is less chance of going wrong.

EXAMPLES

1. Magnetic course SE by S, variation ½ pt. E, find true course. Variation is E, so true course is ½ pt. to the right, which is SSE ½ E.

2. Magnetic course, N 30° E, variation 10° W, find true course. Variation is W, so true course is 10° to the left, which is N 20° E.

3. Magnetic course is 280°, variation 25° W, find true course. Variation is W, so true course is to the left (subtract), which gives 255°.

To change a true course into a magnetic course the rule must be reversed, easterly variation being applied to the left.

Example. True course (from chart) 210°, variation 14° W, find the magnetic course. Since the variation is west, the true course is to the left of the magnetic course, so the magnetic course is to the right of the true course and is 224°.

If the student has difficulty with this subject he will find it of assistance to mark out a compass on a circular piece of cardboard and to mark a similar one on a larger piece of cardboard and put a pin through the centers. The small compass may then be turned into any position desired; the small card will show magnetic courses while the larger card shows true courses.

DEVIATION

The direction of the compass needle at any time will be affected not only by the variation at the place but also by any iron or steel which happens to be near enough to exert a magnetic attraction on the compass. In iron and steel vessels this attraction is very great and consequently it is of the utmost importance that the navigator should understand the nature of the error produced and know the methods of finding its amount and making allowance for it, as well as the methods of adjusting the compass so as to get rid of this error so far as possible.

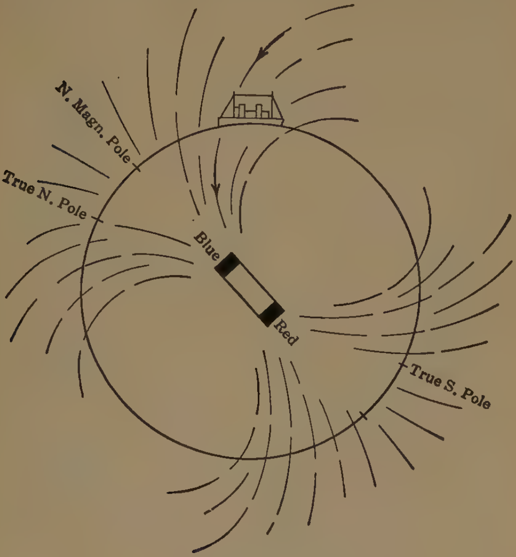
NAMING THE DEVIATION

The angle through which the compass is turned by this attraction of iron is called the *deviation*. It is called **east** if the N end of the compass is drawn to the **east** (right) of the magnetic north; it is west if the N end of the compass is drawn west (left) of magnetic north.

When the correct magnetic direction is to the right of the compass direction the deviation is east; when the magnetic direction is to the left the deviation is west.

MAGNETISM

The deviation is due chiefly to the attraction of the iron and steel of the hull, partly to electric currents and partly to iron in the cargo. Variation and deviation are both due to magnetism; the first is due to the magnetism of the earth itself while the second is due to the magnetism of the ship. Unlike variation, the deviation is different for every different heading of the ship, because as the ship turns, the iron stands in a different relation to the compass needle; this is what makes it so complicated and difficult. It also makes it all the more important to understand it.



The Earth a Magnet.

It is first necessary to understand that the earth itself is a great magnet having north and south poles like any other magnet. Like all magnets it has the power to magnetize other bodies under the right conditions. When a steel vessel is built she remains in the same position for a long time and becomes magnetized and has a north pole and a south pole, their positions in the hull depending upon the direction of her head while building. The hammering and riveting of the plates greatly aid this magnetizing process and make the magnetism more permanent. After she is launched some of this magnetism will be quickly lost but much of it will always remain.

If a ship is built with her head to the north, her north magnetic pole will be toward the earth's magnetic north (forward), and, if she is built in the northern hemisphere, it will also be low down in the hull, while the south pole of the ship will be to the magnetic south (aft) and higher up in the hull. (Fig. 10). According to custom, the north pole is shown in *red* and the south pole in *blue*. These two poles are not on the same level on account of what is called magnetic *dip*. If you should suspend a magnetized needle so it could turn freely in any direction it would dip down toward the pole at quite a large angle unless you happened to be on or near the magnetic equator. In the northern part of the United States the north end of a free needle dips more than 70° below the horizontal line. The north end of a compass needle also would dip (in the northern hemisphere) if it were free, but it is suspended in such a way that it cannot dip.

Before we describe the adjustment of the compass we must explain about the attraction and repulsion of the magnetic poles. It is a general rule that two magnetic poles of the same kind (both N or both S) will repel each

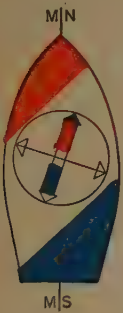


FIG. 11.

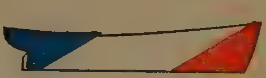


FIG. 10.

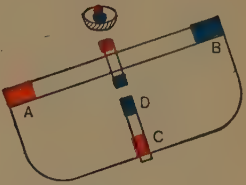


FIG. 14.

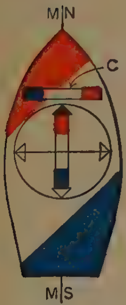


FIG. 12

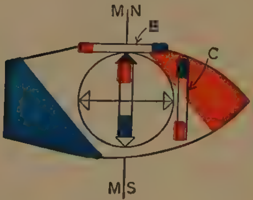


FIG. 13

other, while two poles of opposite kind will attract each other. If you should hold the N end of a magnet near the S end of another magnet you would feel the magnets drawing toward each other. If you let them move freely they would come together with a click. If you reverse one of the magnets so that their north poles are together, it will require some force to hold them in that position, because they repel each other.

There is one apparent exception to the above general rule. The magnetic pole of the earth which is called north attracts the end of the compass needle that we call north, just contrary to the rule. This is owing to the fact that these poles were both named long before the law of attraction and repulsion was understood.

Thinking of our steel vessel as a big magnet, we see that its effect on the compass needle is just as though we held an ordinary steel bar magnet near the compass in a position corresponding to the magnetism of the vessel. If we knew just where the ship's poles were located, we could tell at once how to compensate for this deviation, for if we placed a bar magnet near the compass and turned its N pole just the opposite way it would neutralize the effect of the ship's magnetism and the compass would then point magnetic north as it should. Since we know very little at first about the magnetism of the ship and we do not know how to place this compensating magnet, we must replace this single magnet by two magnets, one placed fore-and-aft, the other athwartships, and regulate their distances from the compass so that the two magnets together will overcome the deviation error.

ADJUSTING THE COMPASS

The deviation is complicated and cannot be compensated at once as though it were due entirely to one cause. The first adjustment to be made is that for "semicircular" deviation, which is the deviation due to the magnetism which has remained in the steel of the hull after building and also to the magnetism temporarily induced in vertical pieces of soft iron. The *sub-permanent* magnetism of the ship (as it is called) is not very changeable except when the vessel is new. The attraction due to vertical soft iron, like the smoke stack, stern post, or boat davits, is very changeable. In the northern hemisphere the upper ends of such pieces have South (blue) polarity and attract the North (red) end of the compass. On the magnetic equator they show no magnetism. In the southern hemisphere the upper ends will show North (red) polarity and will repel the North (red) end of the compass. This attraction increases in intensity as the vessel approaches the earth's magnetic poles. It is evident that if we tried to compensate such magnetic effect by using a permanent steel magnet near the compass that the adjustment would hold good for only one place. If the vessel changes her latitude, the compass must be corrected again, because the effect of the steel magnet remains the same while the effect of vertical iron undergoes a change. The only help for this is to find by observations in two different latitudes how much of the semicircular deviation is due to vertical iron. It is then possible to determine the position of a soft-iron corrector near the compass which will offset the error produced by the other soft iron (the funnels, etc.). When such a piece of iron (called a Flinder's bar) is once placed in the right position it corrects this error for all latitudes, because as the magnetism of the smoke stack, etc., changes with latitude, the magnetism of the correcting bar also changes in the same way, and keeps the compass always in its correct direction. When adjusting a compass for the first time and nothing is known about the effect of vertical iron it is considered a good plan to put in a Flinder's bar that will remove all but about 10° of the deviation on E and W. This is to be changed afterward when more is known about the effect of vertical iron.

SEMICIRCULAR DEVIATION

To come back to the sub-permanent magnetism of the ship; we may suppose this error to be divided up into two parts, one acting fore-and-aft, and the other acting athwartships. We know that if we should take two small magnets and place them near the compass, one fore-and-aft and one athwartships, we could, if we knew the positions of the ship's magnetic poles, find positions for these magnets such that their combined effect on the compass would be just the same as the effect of the magnetism of the ship's iron. In correcting for this error we place two magnets in the positions mentioned, only we turn their North ends just the *opposite* way so that their magnetism opposes that of the ship.

Suppose that a ship is built with her head NE. The

N pole of the ship's iron will then be on the port bow and the S pole will be on the starboard quarter as shown in Fig. 11. When the ship heads magnetic North the ship's N (red) pole will repel the N end of the compass off toward the east (easterly deviation); so the magnet *C* must be placed at such a distance (N end to starboard) that its N end will repel the N end of the compass back to its true position, Fig. 12.

If we now suppose the vessel to be headed magnetic east, as in Fig. 13, we see that the magnetism of the vessel would repel the N end of the compass to the west (westerly deviation). Magnet *B* must be so placed (S. end forward) that it brings the compass back to its correct position.

To place these two magnets in position, the ship's head is swung round until she heads correct magnetic North. This direction may be determined either by the compass itself, allowing for the known deviation on that heading, or else by means of the pelorus and sun's magnetic bearing as explained later. With the ship steadied on this heading place the athwartship magnet (*C*) in position. Move it to or from the compass until the compass reads exactly N, then fasten the magnet in place. If the vessel has a compensating binnacle, place the magnets in the trays and raise or lower the tray until the compass reads N. Next head the ship magnetic East, and place a fore-and-aft (*B*) magnet in such position as to cause the compass to read exactly East. This adjustment by means of the two magnets should correct the compass for headings on all four cardinal points, but it is a good plan to head the ship magnetic South and try the compass again. If it does not read quite South the magnet *C* may be moved a little so as to make the compass come half-way back to South. In the same way the ship may be headed West and the fore-and-aft magnet readjusted so as to correct half the difference. The number of magnets to be used and their distance from the compass must be found by trial.*

QUADRANTAL DEVIATION

That part of the error known as *quadrantal* deviation is next to be corrected. This error will be greatest when the ship heads NE, SE, SW or NW. It is caused by the magnetism induced by the earth's magnetic force in horizontal pieces of iron such as the ship's beams. It is corrected by placing the two soft iron spheres in position, one each side of the compass. The ship is first headed magnetic NE and the distance of the spheres from the compass adjusted, in or out, until the compass indicates a NE course. It is a good plan to have these quadrantal correctors already in about the right position before correcting for the semicircular deviation. The magnetic conditions surrounding the compass are then about the same as they are to be when the adjustment is complete and it may save the necessity of making a second adjustment of the two magnets. The deviation should now be tested when the ship is headed SE, SW and NW.

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* For further details consult Special Publication No. 96 of the U. S. Coast & Geodetic Survey (from Superintendent of Documents, Washington, D. C., price 15 cents); and "A Practical Manual of the Compass," U. S. Naval Institute, Annapolis, Md., price $1.75; or Bowditch, "American Practical Navigator."

HEELING ERROR

The *heeling* error is due in part to the fact that when the vessel is heeled over the iron beams are no longer horizontal iron, but have, to some extent, the effect of vertical iron. In the northern hemisphere their upper ends will have south (blue) polarity (*A–B*, Fig. 14). This error is not large except when the ship is headed about North or South. The heeling error is also partly due to the vertical component of the sub-permanent magnetism (*C–D*, Fig. 14). It is corrected by placing a small steel magnet vertically beneath the center of the compass, N end up in the northern hemisphere. The N end of this magnet has just the opposite effect to that of the upper ends of the beams. (Fig. 14.) When the latitude changes it is necessary to readjust the height of this magnet. The heeling error is detected by noting the vibration of the compass card when the ship is headed N or S and is rolling. The corrector is raised or lowered until this vibration is made as small as possible.

The description of the adjustment of the compass has been given with considerable detail because it is important that the navigator should understand the forces that are continually affecting his compass. These adjustments are usually made by an expert compass adjuster, and their importance is so great that the navigating officer should not undertake to alter the adjustments until he has had some instruction by a person who thoroughly understands the matter. This does not excuse him from understanding the methods of adjusting, because the time is coming when every applicant for a master's license will be required to know the adjustments of the compass. After the compass is adjusted, small errors will undoubtedly remain. These are always determined and given to the navigator in the form of a table of deviations (called *residual* deviations to distinguish them from the natural deviations). Such a table will be of assistance, but it must not be relied upon implicitly. A change in the latitude or a change in temperature will alter the deviations. If the vessel has continued on one course for several days and then suddenly changes her course there is likely to be a large deviation of the compass toward the old course due to temporary induced magnetism. Presence of electric currents, or changes in iron cargo will affect the deviation. The only safe rule is to determine the deviation every time the course is changed, or at least once per day.

Although the navigator may not feel qualified to adjust his compass there is one thing he may safely do if he is fortunate enough to have a compensating binnacle. After the compass has been adjusted the reading of the height of the magnet trays on the scale should be recorded. Then with the ship heading east the fore-and-aft tray may be raised exactly one inch on the scale, and the amount of the change in the deviation noted (by the sun or by a distant object) and the direction in which the change occurs. These should all be recorded. Then the tray should be moved back to its original position and the deviation tested to see if it is the same as at first. Next the same tray should be lowered one inch and the same test repeated. The tray is then set again in its original position. After this test is recorded the same operation should be gone through with for the other (athwartship) tray, only in this case the ship must be headed north. From these records it is easy to figure out at any time just what change in the height of a tray will produce any desired change in deviation. If it is found, for example, that the deviation is 6° E when heading N, then from the records made the navigator can figure out how much to raise or lower the athwartship magnets to produce a deviation of 6° W and correct the compass. In this way the deviations may be kept small at all times. All such changes in adjustment should be verified by azimuth observations at the first opportunity. This method of correcting is useful when the correction for vertical soft iron (Flinder's bar) has not been made at all or is known to be faulty.

PROBLEM

After the compass is adjusted the following tests are made: Ship heading N, raising *C* (athwartship) magnets one inch (from 9.50 to 8.50 on scale) causes 13° Easterly deviation. Lowering same from 9.50 to 10.50 causes 11° W deviation. Ship heading East, raising *B* (fore-and-aft) magnets one inch (10.0 to 9.0) causes 7° W deviation; lowering same (10.0 to 11.0) causes 5° 30′ E deviation. Ship heading NE, moving spheres in one inch (10.5 to 9.5) causes 4° W deviation. Moving spheres out one inch (10.5 to 11.5) causes 3° E deviation.

(*a*) Suppose that it is found later that there is a deviation of 2° E when the ship is heading about East. Which magnets should be moved, which way and how much?

Ans. Raise *B* 0.29 in.

(*b*) If there is a Westerly deviation of 3°, ship heading South, which magnets should be moved, which way and how much?

Ans. Lower *C* 0.23 in.

(*c*) If there is a deviation of 2° E, ship heading SW, which way should spheres be moved, and how much?

Ans. In 0.5 in.

FINDING THE DEVIATION

Three ways of finding the deviations will now be described. These may be either the natural deviations, before any compensation has been made, or the residual deviations, after the adjustment is finished; the method is the same for both.

In describing these methods it will be necessary to use the term *bearing*. The bearing of a line is the angle it makes with the meridian. The angle it makes with the true meridian is its true bearing; the angle with the magnetic meridian is the magnetic bearing; the angle with the compass needle is the compass bearing. It is just like the course except that it refers to the direction of some line such as the line from the ship to a lighthouse.

BY THE BEARING OF A DISTANT OBJECT

Select a distant object such as a lighthouse or some landmark whose bearing may be taken by compass. As the vessel is swung she will change her position somewhat so the object must be far away, say 6 miles or more, so that its bearing will not be changed. Swing the ship so that she heads N by compass and take the bearing of the object. This may be done by means of the azimuth sight shown in Fig. 15. Record this bearing in a table like that on p. 38. Then swing the ship to head NE and again take the bearing of the object. Do the

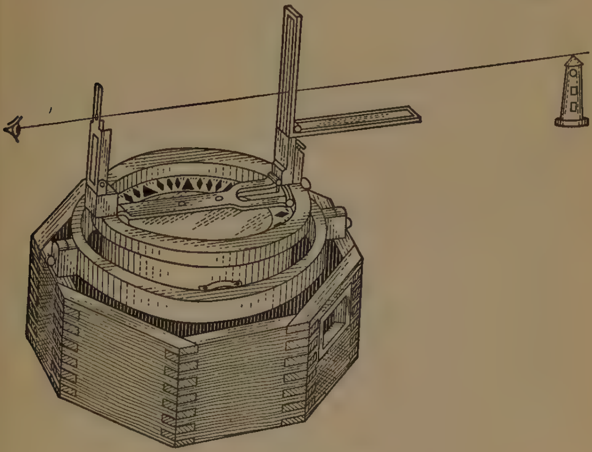

FIG. 15. Azimuth Sight.

same on E, SE, S, SW, W and NW. The results are shown in the table below.

To find the correct magnetic bearing take the average of the bearings for N and for S, then the average bearing for E and for W, then for NE and for SW, and finally for SE and for NW. All four of these average results should be nearly the same. The average of these four is the correct magnetic bearing (202°). To find the deviations take the difference between this correct magnetic bearing and each one of the observed bearings. Name these deviations according to the rule on p. 24.

Ship's Head by Compass	Compass Bearing of Object	Average Opposite Headings	Deviations
N	199°		3° E
NE	204.5		2.5 W
E	208		6 W
SE	208		6 W
S	206	202°.5	4 W
SW	200.5	202.5	1.5 E
W	196	202.0	6 E
NW	195	201.5	7 E

4)808.5
202.1
(say 202°)

BY A RANGE

Sometimes it is possible to find a range fixed by two lighthouses, or other objects, the magnetic bearing of which is known. The magnetic bearings of some ranges may be found on the charts or in the *Coast Pilot.* If the compass bearing of the lighthouses is taken when the vessel is on the range line and headed on the eight principal points as described above, the deviations may be found by taking the difference between the observed bearings and the known magnetic bearing. (See rule on p. 24.)

BY THE SUN

When the observation is made at sea the preceding methods do not apply, so we must depend upon observed bearings of the sun. The bearing may be taken on the heading the ship happens to have at the time, or she may be swung by the helm and steadied on the different headings so as to obtain a table of deviations like that shown on p. 38. The sun's bearing may be taken either by the shadow pin (Fig. 16) or by the azimuth sight* (Fig. 15). By means of the table of Azimuths of the sun (Hydrographic Office Publication No. 71), the sun's *true* bearing may be found as explained on p. 191. The difference between the compass bearing of the sun and the true bearing of the sun is the total error of the compass, that is, the variation and the deviation together. To find the deviation it will be necessary to take the amount of the variation from the chart and deduct this from the total error. The error remaining is the deviation. Name this by the rule on p. 24.

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* The sight shown in Fig. 15 has a mirror which throws a thin strip of sunlight on to the compass card when the sight is directed toward the sun; this makes it unnecessary to look directly at the sun when taking its compass bearing.

The azimuth sight (or better still, the azimuth ring) will give the most accurate results. If an azimuth sight is not at hand the shadow pin may be used. If the pin is used it should be remembered that the sun's bearing is at the opposite point of the compass from the shadow itself. If the pin is not perfectly straight it may be read in two positions and the mean of the two used as the correct reading; that is, after reading the bearing of the shadow, turn the pin half-way round and read again in this second position. For example, if the shadow reads 282° in the first position and 280° in the second position, the true reading is 281°. Subtracting 180°, the bearing of the sun by compass is 101°. If the sun's true bearing by tables is 91° the total error of the compass is 10° W. (It is W because the true direction is to the left.) If the

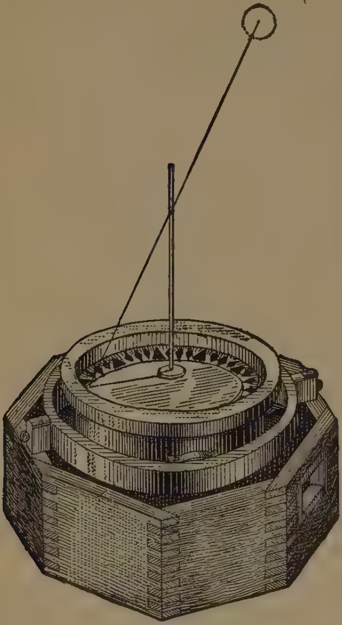

Fig. 16. Shadow Pin.

variation by chart is 16° W, the magnetic bearing is 107° and the deviation is 6° E, the magnetic bearing being to the right of the compass bearing.

CORRECTING A COMPASS COURSE FOR DEVIATION

To correct a compass course (or a bearing) for deviation in order to find the magnetic course (or bearing) we proceed in the same way as when correcting for variation, that is

if the deviation is East the correct (magnetic) direction is to the right of the compass direction on the card.

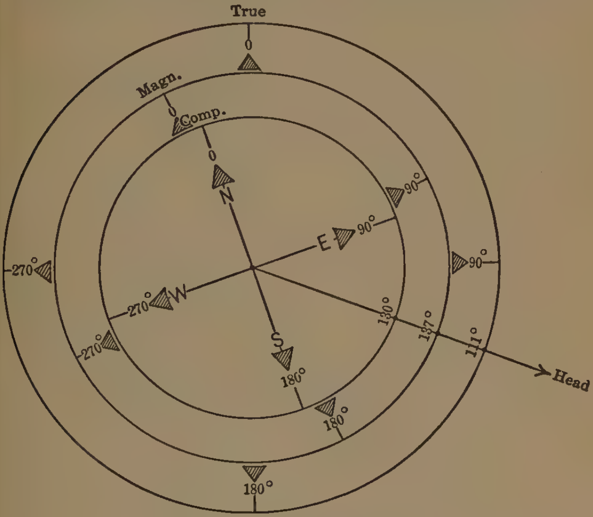

FIG. 17. Deviation 7° E.

when looking from the center of the compass along the direction in question. For example, if the compass course is S 50° E (130°) and the deviation is 7° E, what is the magnetic course? According to the rule the 7° should be applied to the right because the deviation is east. This gives S 43° E (137°) as the magnetic course. (Figs. 17 and 18.) If the variation is 26° W the true course is found by applying 26° (to the left) to the magnetic course which gives S 69° E (111°) for the true course. An examination of the diagram will show that the rule gives the correct result. As another example, suppose that the compass bearing of an object is 220° and that the deviation is 10° W. By the rule we should apply the 10° to the left which gives 210° for the magnetic bearing of the object.

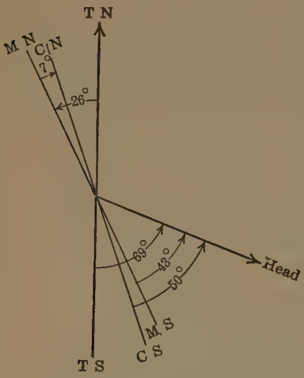

FIG. 18. Deviation 7° E.

CORRECTING FOR HEELING ERROR

When the ship is not on an even keel, there is an attraction on the needle which does not exist when she is on an even keel. Although this error is supposed to disappear when the compass is adjusted, there is likely to be some error remaining after the adjustment and an error will probably appear if the vessel changes her latitude. This heeling error can be detected by noticing what changes take place in the deviation when the ship is heeled by different angles. This is best done when she is headed magnetic North or South and is rolling slowly. The correction, when found, is applied to the course in exactly the same way as deviation.

TO CORRECT FOR WIND, OR LEEWAY

The effect of wind in altering the course of a vessel has nothing to do, in reality, with the error of the compass, but since the allowance for leeway is made in the same manner as the corrections for variation and deviation it will be explained in connection with those errors. If the wind is on the port side of the vessel (port tack), she will slide off to starboard and the true direction is therefore to the right of the direction indicated by the keel (Fig. 19). The effect of leeway on the port tack (or wind on left) is just the same as the effect of Easterly variation or deviation. The angle of leeway may be estimated by the appearance of the ship's wake, or it may be measured directly by taking the angle between the keel and the log line.

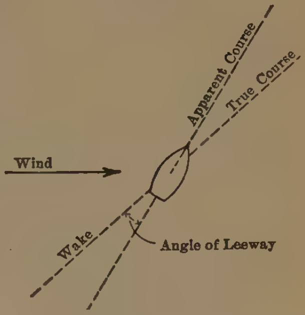

FIG. 19. Leeway.

If on the port tack, mark it E; if on the starboard tack, mark it W; and then correct the course just as for variation.

Example. A vessel is sailing SSE (after correcting for variation and deviation), with the wind NE; the leeway is ½ point. What is the true course? The vessel is on the port tack, so the correction is ½ pt. E, therefore apply ½ pt. to the right, which gives S by E ½ E for the true direction.

In correcting for variation, deviation, and leeway, it is convenient to combine all three into one "error of compass" and apply this to the course, as shown below.

Compass course	Variation	Deviation	Leeway	Error	True course
N 35° E	12° W	10° E	5° E	3° E	N 38° E
S 20° E	12° W	8° W	2° W	22° W	S 42° E
241°	12° W	2° E	6° E	4° W	237°

TO SET A COURSE SO AS TO ALLOW FOR LEEWAY

To alter the course steered so that the course actually made good is the course desired, apply to the compass course the estimated amount of leeway and steer by this new course. If the wind is on the port tack steer a course which is to the left of the compass course already set; if on the starboard tack steer a course which is to the right of the compass course.

The amount of leeway may be estimated in case of a sailing vessel by noting the angle which the log line makes with the fore-and-aft line, or by the appearance of the wake. For a steam vessel it must be found from previous experience, comparing the courses steered with the courses made good in various winds.

THE PELORUS

The pelorus is a compass card, without a magnetic needle, hung in gimbals and fitted with sight vanes for taking azimuths of the sun or bearings of objects on shore. (Fig. 20.) It is sometimes called a "dumb compass";

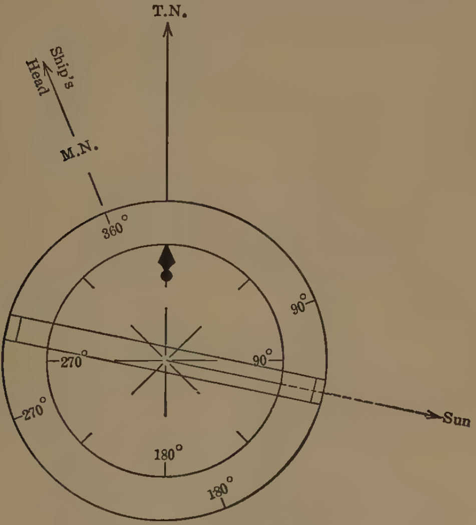

FIG. 20. The Pelorus.

it is not a real compass because it has no magnetic needle. The outer metallic ring has degrees marked upon it, the 360° and 180° marks being on the fore-and-aft line or parallel to it. This ring is not movable. Fitted into this ring and pivoted on the same center is a circular glass plate which is marked with the degrees and also with the points of the compass. This glass plate can be turned through any angle and clamped in any position. Above the glass plate and pivoted on the same center is a horizontal bar carrying the sight vanes. On each end of this bar are index marks for reading the bearings.

To head the ship on any desired magnetic course, say magnetic North, as for instance when adjusting the compass, turn the glass plate until the degree of the variation coincides with the fore-and-aft line of the outer ring. Turn to the right if variation is west; to left if variation is east. The degrees on the glass plate then correspond to true bearings. Next move the sight vane until it reads the sun's true bearing (on the glass plate) at the instant. Then turn the ship with the helm until the sight vanes are pointing at the sun. Steady her on this course and she will be headed magnetic North. In order to perform this operation quickly, it is necessary to have prepared a table of the sun's true bearings and the corresponding local times and to have the watch set accurately to local time. The true bearings can be found from Hydrographic Office Publication No. 71 if you know the sun's declination (or the date) and the latitude. For the use of this table see p. 191; for the meaning of local apparent time see p. 174. If desired, the 360° mark of the glass plate may be set at the fore-and-aft line of the pelorus so as to make the degrees correspond to magnetic bearings. Then the table should contain the magnetic bearings of the sun instead of true bearings.

To take a compass bearing of an object with the pelorus, sight the vanes toward the object, clamp the bar, and, at the same instant, note the heading of the ship by standard compass. Then turn the glass plate until the degree of the ship's heading is on the dead-ahead mark; the bearing observed (against the mark on the bar) will be the compass bearing. If this bearing is now corrected for deviation and for variation it will be the true bearing of the object.

THE SPERRY GYRO-COMPASS

This compass depends for its operation upon an entirely different principle from the magnetic compass and is independent of magnetic conditions. A wheel (gyroscope) with its axis horizontal is mounted on very delicate bearings and is kept spinning at a high velocity by means of electric power. The action upon this gyroscope of the earth's rotation about its axis is such that it directs the wheel axis toward the *true* North, somewhat as the earth's magnetism directs the compass needle toward the magnetic North. Such a compass when properly mounted, driven and regulated has neither deviation nor variation. It has certain small errors, but these are corrected automatically so that no correction has to be applied to the courses or bearings. These instruments have been installed in most of the vessels of the U. S.

Navy and in many large merchant vessels. For further details see "A Practical Manual of the Compass," U. S. Naval Institute.

For log, lead, and compass see also Knight, *Modern Seamanship.*

PROBLEMS

1. Correct the following magnetic courses for variation: N 65° E, var. 18° E; S 69° E, var. 18° E; S 40° E, var. 17° E; S 10° W, var. 17° E.

Ans. N 83° E, S 51° E, S 23° E, S 27° W.

2. Correct the following compass courses for variation and deviation: 170°, var. 11° W, dev. 5° E; 210°, var. 10° W, dev. 3° W; 250°, var. 9° W, dev. 1° W; 271°, var. 9° W, dev. 3° E.

Ans. 164°, 197°, 240°, 265°.

3. Correct the following magnetic courses for variation: N 30° E, var. 5° E; N 54° E, var. 4° E; East, var. 4° E; S 80° E, var. 4° E; S 49° E, var. 3° E.

Ans. N 35° E, N 58° E, S 86° E, S 76° E, S 46° E.

4. Correct the following magnetic courses for variation: NNE, var. 1 pt. E; NE by N, var. 11° ¼ W; S 45° E, var. 14° E; S 10° W, var. 2° W; N 80° W, var. 5° E; 110°, var. 4° E; 260°, var. 20° W; NW by W, var. 6° W.

Ans. NE by N, NNE, S 31° E, S 8° W, N 75° W, 114°, 240°, NW by W ½ W.

5. Correct the following courses:

Compass course	Variation	Deviation	Leeway	Tack
NE by E........	1 pt. E	½ pt. W	¼ pt.	Port
E by S..........	1 pt. E	1 pt. E	¼ pt.	Starboard
SW by S.........	1 pt. E	½ pt. E	½ pt.	Starboard
NNW...........	1 pt. E	½ pt. W	¼ pt.	Port

Ans. NE by E ¾ E, SE by E ¼ E, SW, N by W ¼ W.

6. Correct the following magnetic courses: SSW, var. 10° W; SW, var. 10° W; WSW, var. 10° W; West, var. 11° W.

Ans. S 12°½ W, S 35° W, S 57°½ W, S 79° W.

7. Correct the following courses:

Compass	Variation	Deviation	Wind
40°	10° W	5° E	5° (port)
100°	9° W	1° W	3° (starboard)
190°	9° W	4° E	8° (starboard)
300°	10° W	3° W	3° (port)

Ans. 40°, 87°, 177°, 290°.

8. Shadow pin reading 317°½; azimuth of sun from tables N 117° E; variation from chart, 18° W; heading, 356°½. Find the deviation.

Ans. 2°½ W.

CHAPTER III

CHARTS

CHARTS are exceedingly important to the navigator, both in deep sea navigation and in piloting. For laying out the track of a proposed voyage he will need an ocean sailing chart, a pilot chart, a variation chart and a great-circle chart; for the daily observations, a position plotting sheet; and when leaving the land or approaching the land he will need charts of the locality in question. It is of great importance that these latter be corrected to date. Charts sold by the regular agents are stamped with the date to which they have been corrected.

CIRCLES

In order to use his chart intelligently the navigator must understand clearly what latitude and longitude are and how they are measured. Before this can be done he must understand the geometry of the circle. In Chapter II we explained that the circumference of every circle is supposed to be divided into 360°. The number of degrees is always the same no matter what the size of the circle may be, but of course on a large circle the degrees will be longer than they are on a small circle. If we draw two lines from the center of the circle to any two points on the circumference they cut off a certain number of degrees of arc; the angle at the center between these two lines contains exactly the same number of degrees as the arc. For a finer division of the circle we subdivide each degree into 60 parts called minutes. When a still finer division is needed we divide each minute into 60 parts called seconds; so we have

$60'' = 1'$
$60' = 1^\circ$
$360^\circ = 1$ circumference
also $90^\circ = 1$ quadrant

Since all circles are divided in the same way we cannot say how long a degree is or how long a minute is unless we know the size of the circle. We can say, however, that on the surface of the earth one degree of a *great circle* is 60 nautical miles, one minute is one mile, and one second is about 100 feet, because we know the size of the earth. In the measurement of distances at sea we use the nautical mile because it is the simplest. Each nautical mile extends over one minute of arc of the earth's surface and subtends one minute of angle at the earth's center. Miles on the earth may be called minutes and minutes may be called miles so long as we mean nautical miles (6080 feet) and so long as the circle is a *great circle*, that is, so long as its center is at the center of the earth.

MERIDIANS AND PARALLELS

For finding latitude and longitude of places on the chart and for taking off courses and bearings the chart is usually covered with what is called a projection, that is, meridian lines extending from pole to pole and crossing the chart from north to south, and parallels of latitude extending east and west. The meridians are great circles; the parallels of latitude are not great circles, except the equator, but become smaller and smaller as we approach the poles. The meridians and parallels may be drawn for every 20°, as on sailing charts, or for every 5° or every 1°, according to the scale of the chart.

LATITUDE AND LONGITUDE

The latitude of a place is the number of degrees and minutes on the earth's surface between the equator and the place, measured north or south along a true meridian. If a certain place is in latitude 38° 51′ North it is 38° 51′ or 2331′ north of the equator.

$$\begin{array}{r} 38^\circ \\ \underline{60} \\ 2280 \\ \underline{51} \\ 2331' \end{array}$$

The sailing distance from the equator to the place would be 2331 nautical miles. The angle at the center of the earth between the equator and the place would also be 38° 51′.

The longitude of a place is the number of degrees and minutes on the equator between the meridian of the place and the meridian from which longitudes are measured. Longitudes are usually measured from the meridian of Greenwich (England) taken as the 0° meridian.

So if we say that the longitude of Havana is 82° 23′ West we mean that if the meridian of Havana is extended down to the equator there will be 82° 23′ on the equator between the 0° meridian and the Havana meridian. If we measure the angle at the pole between these two meridians we shall find the same number of degrees and minutes, 82° 23′. If we count the degrees on the parallel of latitude that passes through Havana we shall find the same number of degrees and minutes (82° 23′) but the length of these degrees is shorter than the length of the degrees on the equator, because the whole circle is smaller, and its center is not at the center of the earth. In this case it would be entirely wrong to say that 1′ on this parallel is a nautical mile.

In order to find the latitudes and longitudes of points on the chart some of the meridians and some of the parallels are drawn across the chart. Along the edges of the chart will be found the degrees and minutes of latitude and of longitude. By means of the scales of minutes on the margins you can find the latitude and longitude of any place on the chart even though there is no meridian or parallel drawn through it. (See the chart on p. 62.)

INFORMATION ON CHARTS

Charts of the oceans, or sailing charts, show the outline of the coast, the positions of the principal ports, and the depths of the ocean. These charts give a large amount of information of importance to the navigator, such as latitudes and longitudes, directions and distances between points, variation of the compass at different places (shown by dotted lines for every 5°), the steamship lanes, and information about currents, winds, etc. The compasses* printed on these charts give the true courses and are usually numbered from 0° at the north right-handed (in the direction the hands of a watch move) up to 360° at the north again. On the pilot charts, issued every month by the Hydrographic Office, the variation curves are drawn for every 1°. These charts also contain information concerning the currents, prevailing winds, storms, ice, and other matters of vital importance to the navigator.

Charts of the coast are drawn to a larger scale than the sailing charts, and show elevations of the land, positions of landmarks, depths of water, directions of currents, locations of rocks and shoals, character of the bottom, and the positions of lighthouses, buoys and beacons. The sectors over which lights are visible are indicated, together with information as to the character of the light. The positions and colors of buoys are shown. In the United States, channel buoys are painted red if on the starboard side of the channel, as you enter from the seaward side, and are marked with even numbers (2, 4, 6, etc.); they are black with odd numbers (1, 3, 5, etc.), if on the port side of the channel. Buoys in mid-channel with vertical black and white stripes show that the channel is narrow and the ship must pass close to such a buoy to avoid danger. An obstruction in the channel is marked by a buoy having red and black horizontal stripes. Turning points in the channel are shown by a ball or a cage on the buoy. A yellow buoy indicates a quarantine station; a white buoy indicates a mooring or anchorage. Complete information regarding lighthouses and buoys of the entire cost of the United States will be found in the lighthouse lists and buoy lists issued by the Lighthouse Service, Department of Commerce.

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* The compass printed on a chart is called a compass "rose," see Chart, p. 62.

The soundings on coast charts are given either in feet or in fathoms, as indicated in the legend on the chart. The figures given are the depths below "mean low water" for the Atlantic coast; "mean *lower* low water" for the Pacific coast. Allowance must be made for the stage of the tide to get the actual depth at any time. The compasses printed on these charts are usually turned through the angle of variation so that they give magnetic bearings at once. You can tell whether they are on true or magnetic meridian by noticing whether they agree with the true meridians which cross the chart. The symbols and abbreviations used on charts are usually explained in the margin of the chart.

INSTRUMENTS

The instruments used in connection with chart work are the dividers, the parallel rulers, and the course protractor. The dividers consist of two metal legs, hinged at one end and terminating in fine points. The points may be set at any desired distance apart and used to transfer distances from one part of a chart to another. The parallel rulers, Fig. 21, consist of two rulers joined by two metal strips and so arranged that they are always parallel. By holding first one ruler firmly in position and moving the other, and then holding the second and moving the first, the ruler may be "walked" across the chart, and any direction on the chart may be transferred from one position to another. The course protractor is a circle, on celluloid or other transparent material, with the degrees (or points) of the compass marked on it, and having a string or an arm pivoted at the center. If the protractor is placed so that the 0° line lies along a meridian and the string or the arm lies along the ship's track, the course may be read off directly from the circle.

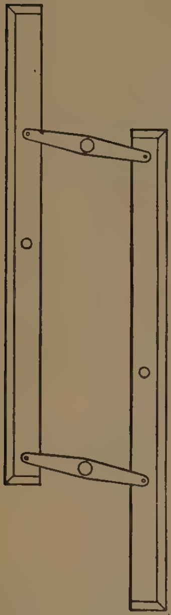


FIG. 21. Parallel Rulers.

CHARTS

The kinds of charts chiefly used by the navigator are the Mercator chart, the Great-Circle chart, and the Polyconic chart.

MERCATOR CHART

The Mercator chart is imagined to be drawn on the surface of a cylinder wrapped around the earth in such a way as to touch it only at the equator, as shown in Fig. 22. When the map is unwrapped and laid flat the meridian lines and the parallels of latitude are straight and are at right angles to each other. The degrees of longitude on this chart are the same length all the way around the equator and are the same in all latitudes. The lengths of the degrees of latitude, however, increase as we go toward the poles. The chart must be so constructed that it will give correct bearings from one point to another. Now if we have made the degrees of longitude the same in all parts of the chart we have evidently made them too long everywhere except on the equator. To preserve the true directions between points on the chart we must increase the latitudes in just the same proportion. For example, in latitude 60° a degree of longitude is really half as long as a degree on the equator; but since on the chart we have made it as long as a degree on the equator it is represented twice too large, and we must therefore make the latitude degrees twice their natural size to preserve the right relation between the two. This increases all the latitudes (distance from the

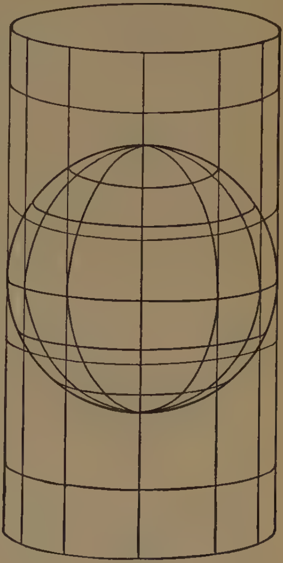


Fig. 22. Projection on Cylinder.

equator) according to a definite mathematical formula which has been figured out. These increased latitudes are called "meridional parts" and will be found in Table 3, of Bowditch's *American Practical Navigator*. The scale of this chart is different in different latitudes and we must make allowance for this fact when measuring distances. The method of doing this will be explained under the "Use of the Mercator Chart".

The most important and useful property of the Mercator chart is that if a straight line is drawn between two ports shown on the chart the angle at which this line cuts all the meridians is the true course on which a vessel must sail *continuously* to go from one port to the other. This track is really a curved line on the earth's surface (see Fig. 23), and is called a *rhumb line*. It is not the shortest possible track, but it is the one generally sailed except when the distance is long. This chart is in constant use in navigation.

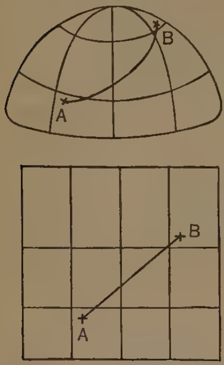


Fig. 23. Rhumb Line or Mercator Track.

GREAT-CIRCLE CHART

A great circle is the largest circle that can be drawn on a globe; its center is always at the center of the globe. A great-circle chart shows every great circle as a straight line and is made by drawing the meridians and parallels on a plane which touches the earth at one point, say latitude 30° N, longitude 30° W, in the middle of the Atlantic Ocean. The meridians are straight, converging lines; the parallels of latitude are all curved, except the equator. This chart is not drawn to uniform scale, and distances cannot be scaled off as on an ordinary land map. But it has one property of great importance to the navigator; every straight line on this chart represents a great-circle track on the earth's surface, that is, the shortest track a ship can sail between two points. To lay out a great-circle track on this chart simply draw a straight line between the points of departure and destination (Fig. 24). If we should stretch a rubber band between these two places on a globe the band would take the position of an arc of a great circle, the shortest track between these points. This is the track represented by the straight line on the chart. It is not convenient to take off the courses from the great-circle chart itself

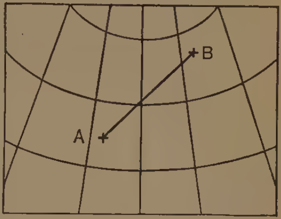


FIG. 24. The Great-Circle Chart.

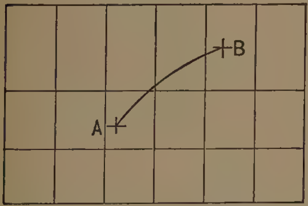


FIG. 25. Great Circle on Mercator Chart.

because the meridians are not parallel to each other, but if the latitudes and longitudes of several intermediate points on the track are read off and transferred to the Mercator chart (Fig. 25), the courses of the different portions of the track may then be found as explained later.

THE POLYCONIC CHART

The Polyconic Chart is little used in Navigation except in case of the Coast and Harbor Charts. It is the best kind of chart for surveying and mapping. Its chief advantage lies in the fact that the same scale applies to all parts of the map.

POSITION PLOTTING SHEETS

For laying down lines of position as explained in Chapter XI, it is convenient to use position plotting sheets. These are blank charts and show simply the meridians and parallels drawn on Mercator's projection on such a scale that 1° of longitude is 4 inches long (Chart No. 3000). These extend from the equator to latitude 61° and come in sheets showing 4°, 5° or 6° of latitude. For example, No. 1 extends from 0° to 6°; No. 6 extends from 30° to 35°; No. 9 extends from 45° to 49°. The longitude degrees are not numbered; they are all of the same length, so they may be used for any longitude. Two large compass roses showing single degrees of true course are printed on each chart.

USE OF THE MERCATOR CHART

To find the latitude and longitude of a point A (Fig. 26), *on the Mercator chart:* Set one point of the dividers on point *A* and the other on the parallel of latitude at *a*; then move the dividers over to the left (or right) margin of the chart, set one point of the dividers on the parallel of *a* and read off the latitude of *A* on the marginal scale at the other point of the dividers.

The longitude is found in a similar manner except that it is read from the scale at the top or bottom of the chart. This may also be done with the parallel rulers. Place the ruler along the parallel of latitude through *a* and move it (parallel) until it passes through *A*. The ruler then passes through the latitude of *A* on the marginal scale at the side of the chart. The longitude is found in a similar way, laying the ruler along a meridian and reading the longitude from the top or bottom of the chart.

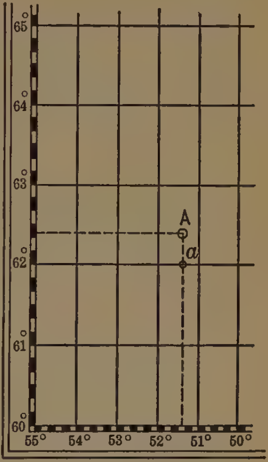
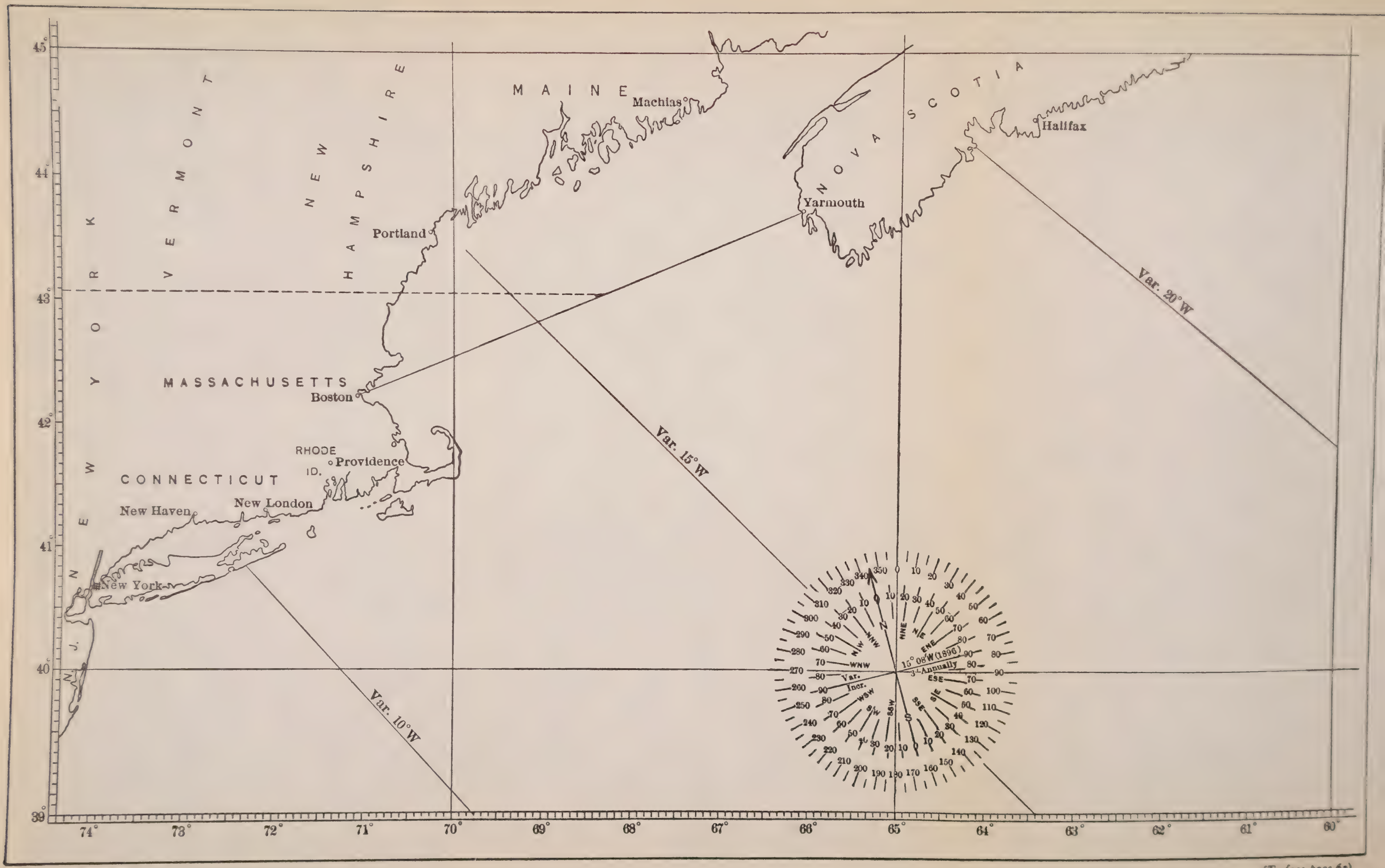


FIG. 26. Mercator Chart.

To mark the position of the ship when the latitude and longitude are known: Place the parallel ruler on a parallel of latitude, move it until it passes through the latitude of the ship as shown by the marginal scale; then draw a light line. In the same way draw another line, parallel to the meridian, corresponding to the longitude of the ship. The intersection of the two lines is her position. If it is desired to locate the position without drawing any lines, the parallel ruler may be held in the first position while the longitude is found by means of the dividers. If the dividers are held against the ruler with one point on the meridian the other point of the dividers will then be on the required position.

To take off a magnetic course: Lay the parallel ruler on the points between which the vessel is to sail; move the ruler over (parallel) to the nearest compass rose shown on the chart. See that the edge of the ruler passes exactly through the center of the compass rose. If the compass rose is magnetic the magnetic bearing is read off directly; this is the course on which to steer provided there is no deviation. If the compass rose is on the true meridian the course read will be a true course and must be changed to a magnetic course by allowing for the variation. To find the compass course (on which to steer) allow for the deviation also.

In order to take off a distance correctly from this chart it is necessary to use the correct scale of miles. otherwise the distance may be badly in error. The scale is changing continuously as we go north or south. A scale of minutes of latitude is placed along the side margin of the chart and these minutes increase in size at just the same rate as the scale increases. If we always



(To face page 62)

use for a scale the length of a minute (mile) in the latitude of the place where we are measuring we will have the correct scale. If the distance covers a large change in latitude we should use the length of a mile at the *middle latitude.* For example, if we wish to know the distance from a point in latitude 42° to a point in latitude 43° we must take for our mile the length of a minute in latitude 42° 30′. It will usually be best to take in the dividers a distance corresponding to, say, 10 miles or 20 miles and step this off along the track; any small distance remaining may be carried over with the dividers to the marginal scale and read off. Be sure not to use the longitude minutes (top or bottom of chart) for a scale of miles. (See Chart, p. 62, and Fig. 26.)

On certain coast charts and on harbor charts drawn on the Mercator projection the scale is nearly the same in all parts of the chart, and a scale of miles is usually shown somewhere near a margin of the sheet. Whenever one of these scales is found on a chart it is safe to use this instead of the scale of minutes along the side margin.

USE OF THE GREAT-CIRCLE CHART

To lay out a great-circle track draw on the great-circle chart a straight line between the point of departure and the point of destination. To find the courses and distances transfer to a Mercator chart the latitudes and longitudes of those points where the track crosses the meridians of the chart. Join these points on the Mercator chart by straight lines; then take off the courses and distances of these portions of the track as described for Mercator's chart.

There are other ways of finding these courses and the distances to sail, some of which will be explained later. On the chart itself will be found instructions for obtaining the courses and distances by certain other methods.

USE OF THE POLYCONIC CHART

Many of the Coast charts and Harbor charts are drawn on the Polyconic projection.* On these Polyconic charts the same scale is good on all parts of the chart and is the same in all directions. A scale of nautical miles is usually shown somewhere on the chart. If the distance to be measured is short take the distance in the dividers and lay it against the scale of miles and read off the distance. If the distance is longer than the scale of miles, take a convenient distance corresponding to, say, 5 or 10 miles in the dividers and step off this distance along the track, counting the spaces; if there is a short distance left over take it in the dividers and carry it over the scale of miles and read off this remaining distance. Courses or bearings may be taken off these Polyconic charts in the same manner as for a Mercator chart because the curvature of the meridians on these Coast charts is so slight as to offer no difficulty. If there is a compass rose on the chart simply carry the direction of the track or line over to the rose and read off the course or bearing the same as for a Mercator chart.

* Many of the recent ones are Mercator.

EXERCISES IN USING THE CHART

1. Select two points on the chart and take off their latitudes and longitudes.

2. By the parallel ruler and compass find the course and distance between these two points.

3. Assume a latitude and longitude for the ship and lay down this position on the chart.

CHAPTER IV

PILOTING

FIXING THE SHIP'S POSITION

To find the position of the ship by cross-bearings: Take simultaneous bearings of two prominent objects (*L* and *H*, Fig. 27), using the azimuth sights or some substitute. Correct these bearings for deviation, and if the chart to be used does not show a magnetic compass, but only a true compass, correct the bearings also for variation. With the parallel rulers transfer the (reversed) bearing of one of the points, *L*, from the compass rose on the chart

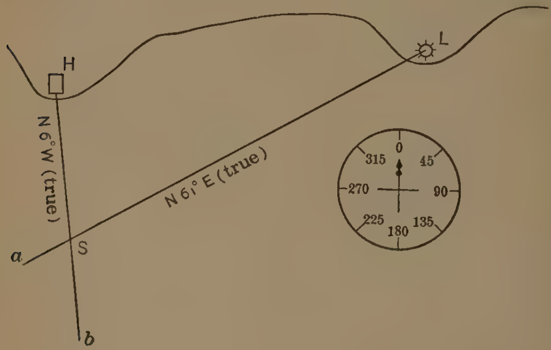


FIG. 27. Cross Bearings.

to the object sighted, and draw a line *La*. Then transfer the bearing of the second object, *H*, and draw a second line, *Hb*. The position of the ship at the time the bearings were taken is at the point *S* where the two lines cross each other. In order to define the position of the ship accurately the objects should be selected if possible so that their bearings differ by about 8 points, or 90°. There will always be some error in taking these bearings and this error will have a much greater effect if the angle between the objects is small.

To locate the ship by two bearings and the run: When there is but one object to be observed the ship may be located by two bearings and the run between. Tables 5A and 5B (Bowditch) enable us to solve the problem without any calculation except one multiplication.

If the bearings are taken in points use Table 5A, in which the angles from ahead are given for every quarter point; if the bearings are taken in degrees use Table 5B, in which the angles from ahead are given for every 2°. Both tables have double columns. In the first column is the distance of the object at the time of the second bearing; in the second column is the distance to the object when abeam. Both tables give these distances for a one-mile run. If the run is not just one mile multiply the run by the numbers in the table.

Suppose that a vessel is on a true course 128° and that the first bearing of the object is 154° (true) the log reading 90.0; at the second observation the true bearing of the object is 182°, and the log reads 91.6. Taking 128° from 154°, and then 128° from 182° we find that the angles from ahead are 26° and 54° respectively; the run is 91.6 – 90.0, or 1.6 miles. From Table 5B we find the corresponding numbers 0.93 and 0.76.

$$\begin{array}{r} 0.93 \\ \underline{1.6} \\ 558 \\ \underline{93} \\ 1.488 \end{array} \qquad\qquad \begin{array}{r} 0.76 \\ \underline{1.6} \\ 456 \\ \underline{76} \\ 1.216 \end{array}$$

The vessel is therefore 1.5 miles from the object at the time of the second bearing, and will pass it abeam at a distance of 1.2 miles.

To locate the ship by a four-point bearing: When the ship, at *S* (Fig. 28), is approaching an object, *L*, the angle on the bow is observed, and when it has increased to four points, as it will be when the ship is at *A*, the log is read. When the ship is at *B*, where the object *L* is abeam (8 pts. off the bow) the log is read again. The distance *AB* is the difference between the two readings of the log (distance run), and is just equal to *BL*, the distance of the ship from the object when the latter is abeam. This method of locating the ship is often used for "taking the departure" when starting on a voyage. This is also called *bow-and-beam bearing*.

To locate the ship by a two-point bearing: Note the log when the object is two points forward of the beam and again note the log when the object is abeam. The ship's distance from the object when abeam is 2½ times the distance run as shown by the log. The same result would be found by taking the log when the object is abeam and again when it is two points abaft the beam.

Some navigators note the log when the object is 1¼ pts. forward of the beam and again when it is 1¼ pts. abaft the beam. The distance from the object when abeam is twice the distance run.

To locate the ship by a one-point bearing: Read the log when the object is 1 point forward or abaft the beam and also when it is abeam. The distance to the object abeam is in this case 5 times the distance run.

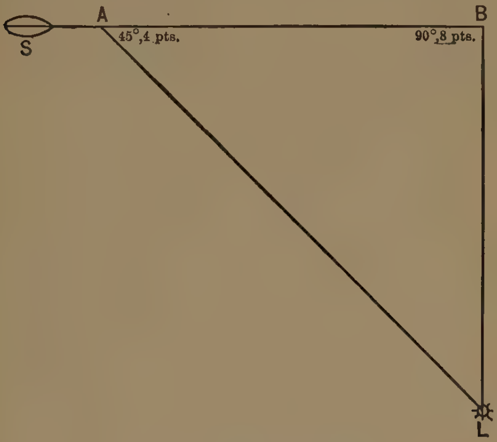


FIG. 28. Four-point Bearing.

Doubling the angle on the bow: In the four-point bearing (Fig. 28), notice that the angle when abeam (8 points) is twice the first angle (4 points). The distance of the ship from the object at the time of the second bearing may always be found by doubling the angle on the bow, no matter what the size of the angle may be.

For example, if the ship is at *A* (Fig. 29), the angle on the bow is 30°, and when she is at *B* it is 60°; then the distance from *B* to *L* is the same as the distance run, *AB*. Any other angles would do instead provided the second angle is twice the first. It is better not to use very small angles.

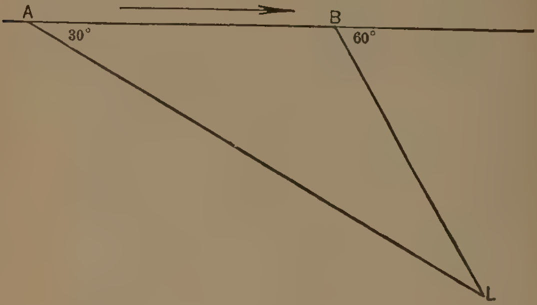


Fig. 29. Doubling the Angle on the Bow.

To find the distance at which the object will be passed abeam: Observe the bearing and read the log when the object is 26½° from ahead, and again observe the object when it is 45° from ahead. The distance run is the distance at which the object will be passed abeam.

There are many other ways of locating the ship by bearings, several of which are described in Bowditch, *American Practical Navigator.*

Finding the distance of the ship by the vertical (sextant) *angle of an object of known height:* Suppose the object to be a lighthouse whose height above the water is known to be 70 ft. With a sextant measure the vertical angle between the top and bottom, say 0° 35′. Look in Table 33, Bowditch, for the height and the angle. The corresponding number in the table will be the distance from the object to the ship in nautical miles (in this case, 1.1 mi.).

If the bearing of the lighthouse is also taken the ship's position may be found on the chart, since both her bearing and her distance from a known point have been found.

MAKING A LIGHT

When approaching the land the navigator should look up his list of lights and ascertain their visibility. The distance at which a light is visible is given on charts for an average height (15 ft.) above the water. If the light is observed from a greater height it can be seen at a greater distance and allowance should be made for this fact. If a compass bearing of the light is taken and corrected for deviation and variation, the navigator knows his distance and direction from the light and can mark his position on the chart.

Example. A light is sighted on the horizon and identified as Navesink lighthouse, having a height of 246 feet. Its true bearing is found to be 273°. The observer's eye is 40 feet above the water. What is the ship's distance from the lighthouse? From the table of distances given in the "Light List" we find for 246 ft. a distance of 18 miles and for 40 feet a distance of 7.2 miles. The distance to the light is therefore 25.2 miles. Laying off a true bearing of 93° and a distance of 25.2 miles from the lighthouse we get the position of the ship.

THE DANGER BEARING

Suppose the ship to be at *A* (Fig. 30), and that between a visible object *L* and the ship are sunken rocks. Draw a line *LB* which just clears all dangers, as shown on the chart. With the parallel rulers transfer this line to the compass rose and find the bearing. Make allowance for deviation and variation. Suppose the compass bearing to be N 30° E. Then whenever the bearing of the object is nearer to North than N 30° E the ship is in danger. When the bearing is farther from North than N 30° E she will pass clear.

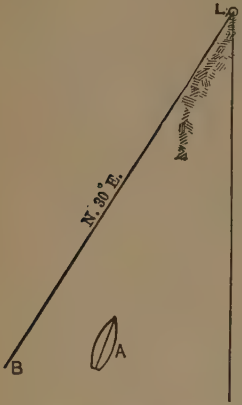


FIG. 30. Danger Bearing.

THE HORIZONTAL DANGER ANGLE

Suppose that there are sunken rocks or other hidden danger at *A* (Fig. 31) and at *L* and *B* are two visible objects shown on the chart. Draw a small circle around the hidden danger at *A* so that anywhere outside this circle the danger will be avoided. With the drawing compasses (or dividers) draw a circle through *L* and *B* and touching the outside of the small circle. With a protractor (or with the parallel rulers and the compass rose) measure the angle at some point *C* (on the larger circle) between *L* and *B*. This is the *danger angle.* Measure with the sextant the angle between the objects *L* and *B*. If this angle is less than the danger angle the ship is outside the large circle and is safe. If the sextant angle is equal to or greater than the danger angle the ship is exposed to danger.

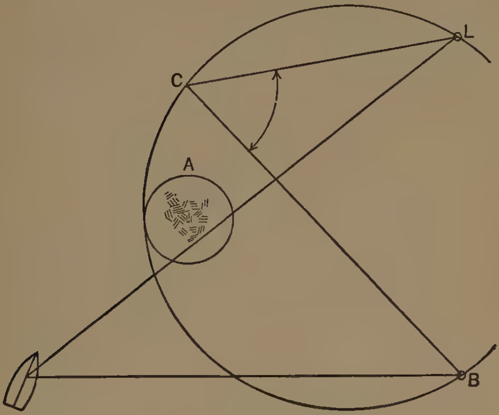


FIG. 31. Danger Angle.

If it is desired to run on the other side of the little circle, draw the large circle so as to touch the small circle on the other side and keep the ship in such position that the sextant angle is greater than the new danger angle.

THE VERTICAL DANGER ANGLE

When there is an object in sight which has considerable height, like a lighthouse, we may determine the angle between the top and the bottom as seen from the point of danger. If we then keep the vessel in such a position that this angle as measured by the sextant is always less than the danger angle we shall pass outside the danger. If we keep the angle always greater we shall pass between the object (lighthouse) and the danger.

For methods of piloting see also Knight, *Modern Seamanship.*

HOW TO LOCATE BY SOUNDINGS

Heave the lead at regular intervals, and keep account of the time, the log, the course, and the depths. Draw a line, representing the course, on transparent paper. Measure off distances, according to the scale of the chart, representing the different positions of the ship when soundings are taken. Write on the paper in the proper places the depths and the character of the bottom. The depths obtained by sounding must be corrected for the stage of the tide. The times of high and low tide as well as the total range in tide can be obtained from the "Tide Tables." (See also p. 268.) Place the transparent paper on the chart, turn the line so that it is in the proper direction for the course steered, then move the paper along on the chart parallel to itself until a place is found where the depths correspond with the depths given on the chart. The position of the ship on the chart at any time is then found from the position on the paper.

There will seldom be found more than one place on the chart where these depths will correspond.

RADIO COMPASS BEARINGS

If the vessel is equipped with radio apparatus it is possible to locate the position by radio compass bearings. In thick weather and when navigating near shore this method is sometimes the only one that can be used. Radio compasses are of two kinds: (1) those placed at fixed stations on shore and (2) those installed on the vessel itself. In making use of the shore stations the vessel signals the station and asks for a bearing; the shore station determines the direction of the signals sent by the vessel and then sends the compass bearing by radio. Having the directions from two or more shore stations of known position the navigator can plot his own position on the chart. Information regarding stations may be obtained from the International Code book and from H. O. charts 2180A and 5172. The exact positions of radio compass stations and other data concerning these stations will be found on the reverse side of the pilot charts, for example, that of the North Atlantic Ocean for March, 1925. (See also H.O. No. 205.)

If the apparatus is on the vessel the navigator need not call a station but he merely identifies the station from which he hears a signal and takes a bearing of that station by means of his own radio compass. Plotting these bearings from the known positions of the stations he can find the location of the ship. The accuracy with which these bearings can be taken is sufficient for the purpose of locating the vessel, and the accuracy of the location becomes greater as the vessel approaches the stations.

SUBMARINE BELLS

A vessel equipped with the necessary microphones can in foggy weather make use of the submarine bell signals which will be found at intervals along certain parts of the coast. If the vessel is swung until the sounds heard on the starboard and port (bow) 'phones are equally loud then the vessel is headed directly toward the buoy giving the signal. If the vessel is in a position from which two signals are heard an approximate location can be obtained.*

PRACTICE PROBLEMS

1. Assume two bearings of objects shown on a chart and plot the position of the vessel from these two bearings.

2. What is the distance of the vessel from Minots Ledge Light (Prob. 15, p. 102) when passing it abeam?

Ans. 2.1 mi.

3. The angle between the top of a lighthouse and the water line is measured with a sextant and found to be 0° 23′. The lighthouse is 120 ft. high. What is its distance? See Bowditch, Amer. Pract. Navigator Table 33.

Ans. 3.0 miles.

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* See Knight, *Modern Seamanship.*

4. A vessel is on a true course 201°. The true bearing of a lighthouse is 170°, the log reading 31.4; when the log reads 33.9 the lighthouse has a true bearing of 132°. Find the distance of the ship from the lighthouse at time of the second bearing and also her distance when the lighthouse is abeam.

Ans. 2.1; 2.0.

CHAPTER V

DEAD RECKONING — MERCATOR SAILING — GREAT-CIRCLE SAILING

THE position of the ship "by dead reckoning" (D. R.) is found by keeping account of the courses and distance sailed from a known position and calculating the amount by which the ship has changed her latitude and longitude.

If a ship sails due North or South the number of minutes change in her latitude is the same as the number of nautical miles run, because she is sailing on a meridian, which is a great circle. To find the new latitude we simply call the miles minutes and then change the minutes to degrees (60′ = 1°). For example, if a vessel in latitude 42° 00′ N runs south 65 miles she will change her latitude 65 minutes, or 1° 05′. Therefore

Latitude left, 42° 00′ N
Change in Lat., 1° 05′ S
Latitude in, 40° 55′ N

so the vessel is now in latitude 40° 55′ N.

In sailing East or West the number of minutes change of longitude does *not* equal the number of miles run, except when the ship is sailing on the equator, because the parallels of latitude are not great circles and their degrees and minutes are shorter than the degrees and minutes of the equator. The number of minutes of longitude depends upon the latitude of the ship as well as upon the number of miles run. In latitude 60°, for example, one mile equals 2 minutes of longitude. We must therefore change minutes into miles by a rule which takes into account the latitude of the place.

PLANE SAILING

If a vessel sails at some angle with the meridian, say 53°, then the number of miles she is N or S of her original position and the number of miles she is E or W of her original position may be found by calculating the two sides of a right triangle; one of these sides being a meridian through one end of the track and the other a parallel of latitude through the other end of the track. In Fig. 32 if a vessel is at *A* and follows the course 233° or S 53° W (or nearly SW ¾ W), for a distance of 10

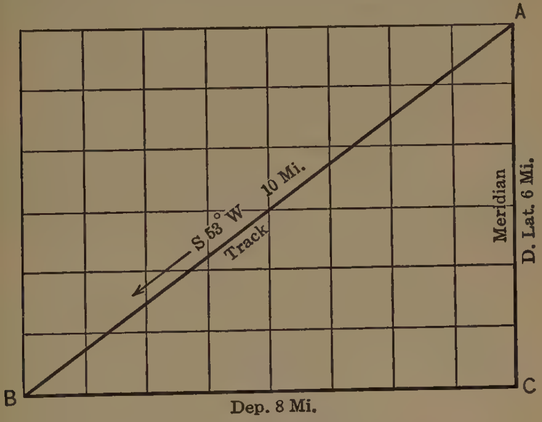

FIG. 32. Plane Sailing.

miles she will arrive at B. The distance that she now is south of A is the number of miles in AC and is called the *difference in latitude* (abbreviated D. Lat., or simply Lat.). From the diagram this is seen to be about 6 miles. The distance she is west of A is the number of miles in BC, called her *departure* (Dep.). From the diagram this is seen to be about 8 miles.

These distances (Lat. and Dep.) may be calculated by logarithms, but the quickest and easiest way to find them is to use the Traverse Table (Tables 1 and 2, Bowditch) in which these numbers are already worked out. The use of logarithms will be explained later. Table 1 contains the Lat. and Dep. (in miles) for every quarter point of the compass and for every mile of distance up to 300 miles. Table 2 contains the Lat. and Dep. (in miles) for every whole degree of the compass and for every mile of distance up to 600 miles.

To use Tables 1 and 2:

Enter the table at the page marked with the degrees or the points of the course, look opposite the distance in miles and find the Lat. and Dep. When the course is found at the top of the page the names "Lat." and "Dep.," are found at the top of the page; when the course is at the bottom of the page the names "Lat." and "Dep." are at the bottom of the page.

The reason for this arrangement is that the Lat. for 10°, for example, is the same number as the Dep. for 80°, or Lat. at the top is Dep. at the bottom, and this arrangement of the tables saves printing the numbers twice.

Notice that the hundreds in the distance column are not repeated except for every 10 miles.

In Fig. 32 the course is 233° or S 53° W, which is nearly the same as SW ¾ W. If we look in Table 1 on the page marked SW ¾ W (bottom of page) and opposite to distance 10 miles we find Lat. = 6.0 and Dep. = 8.0. Since the course is at the bottom of the page we take the words Lat. and Dep. at the bottom of the page.

If we look in Table 2 on the page marked 53° at the bottom we find opposite distance 10 miles Lat. = 6.0 and Dep. = 8.0.

The Lat. should be marked N or S according as the course is taking the vessel north or south. In the 360° system any course between 0° and 90° or between 270° and 360° carries the vessel north and the Lat. is N. Any course between 90° and 270° carries the vessel south and the Lat. is S. The Dep. should be marked E or W according as the course takes the vessel east or west. Any course between 0° and 180° carries the vessel east. Any course between 180° and 360° carries the vessel west.

If the triangle in Fig. 32 is now laid down on a chart (Fig. 33) it will be seen that each mile of Dep. is greater than 1′ of longitude; in this case 8 miles of Dep. equal about 12′ of longitude. The rule for finding the number of minutes in the difference in longitude (D. Lo.) is given under "Parallel Sailing." (See p. 86.)

For practice in using tables 1 and 2 we give the following examples:

Example 1. Course S by E, Dist. 10 miles. Required the D. Lat. and the Dep. Look in Table 1 and find course S by E, a one-point course. Opposite Dist. 10 mi. we find Lat. = 9.8 mi. and Dep. = 2.0 mi.

Example 2. Course SW by W, Dist. 10 mi. This course is over 4 points and is therefore at the bottom of a page; opposite 10 miles we find Lat. = 5.6 and Dep. = 8.3.

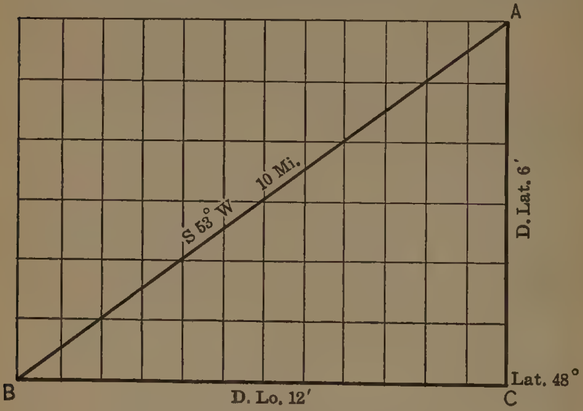

FIG. 33. The Triangle on the Chart.

Example 3. Course S 56° W, Dist. 10 mi. Look in Table 2 for the page marked 56°; this is more than 45° and the degrees will therefore be at the bottom of the page. Opposite the distance 10 miles we find Lat. = 5.6 and Dep. = 8.3.

Example 4. Course 5°, Dist. 50 mi. On the page marked 5° at the top and opposite Dist. 50 we find Lat. = 49.8 and Dep. = 4.4.

Example 5. Course 200°, Dist. 800 mi. This course is 20° more than 180°, so we find it at the top of a page. The Dist. is greater than any Dist. in the table, so take out Lat. and Dep. for 400 mi. (half the Dist.) and double the numbers. The numbers in the table are Lat. = 375.9, Dep. = 136.8. Multiplying by 2, the required numbers are Lat. = 751.8, Dep. = 273.6.

Notice that when the course is greater than four points, or 45°, the Dep. is greater than the Lat.

LAT. AND DEP. BY LOGARITHMS

If it is desired to find the Lat. and Dep. by trigonometry it may be done by the following rule:

Add together the log (logarithm) of the distance and the log cos (log of cosine) of the course; the result is the log D. Lat.

Add together the log distance and log sin (log of sine) of the course; the result is the log Dep.

The logarithms of numbers (Dist., Lat., or Dep.), will be found in Table 42, Bowditch. *To find the log of any number* find the first three figures in the left hand column and the fourth figure at the top of one of the columns. The number in the table in this column and on this line is the decimal part of the logarithm. At the left of the decimal point we must write in a number called the *characteristic*, or *index*. This number is always *one less* than the number of figures in the given number to the left of its decimal point. For instance, if the number is 1206.0 the characteristic is 3; if the number is 120.6

its characteristic is 2; if the number is 12.06 its characteristic is 1. The complete log of 1206 is 3.08135.

To find a number corresponding to a log look in Table 42 for the nearest log corresponding to the decimal part of the given log. On the same line at the left will be found the first three figures of the number and at the top of the column the fourth figure of the number. The characteristic shows where to place the decimal point. If the characteristic is 1 there will be two figures to the left of the point; if the characteristic is 2 there will be three figures to the left of the decimal point, always one more figure than is shown by the characteristic.

For example, the number corresponding to 1.53705 is 34.44 since this log is nearly the same as .53706 found in the table.

To correct a logarithm for the fifth figure: Find the log for the first four figures, then in the short columns at the right-hand side of the page find the number in the right-hand column that corresponds to the 5th figure in the left-hand column. Add this to the log already found. For example, find the log of 435.33. The log of 435.3 is 2.63879. Opposite 3 in the short column we find 3 which is to be added. The final log is 2.63882.

To find the fifth figure of a number: Find the next smaller log in the table. Find the excess of the given log and opposite this in the short column is the 5th figure. For example, find the number corresponding to 0.49520. In the table we find that 0.49513 corresponds to 3.127. 0.49520 exceeds 0.49513 by 7. Opposite 7 in the short column is 5, the fifth figure. The number is therefore, 3.1275.

The log sines and cosines named in the preceding rule (as well as logs of tangents, cotangents, secants, and cosecants) will be found in Table 44, Bowditch. *To take out a log sin* find the degrees at the top of the page and the minutes, if any, at the left-hand side. The number in the column marked "sine" and on the line of the minutes is the log sin required. If, however, the angle is greater than 45° the degrees will be found at the foot of the page and the minutes at the right. The log cos is found in a similar way in the column marked "cosine." If the degrees are at the top the names are at the top; if the degrees are at the bottom the names are at the bottom.

To find an angle corresponding to a log sin (or log cos) in Table 44, look in the column marked "sine" (or "cosine") for the nearest log. If the name is at the top of the page take the degrees from the top and the minutes from the left-hand side; if the name is at the bottom take the degrees from the bottom and the minutes from the right-hand side.

Example. True Course 31°, distance 58 miles. Find the Lat. and Dep. by logarithms:

log 58	1.76343	log 58	1.76343
log cos 31°	9.93307	log sin 31°	9.71184
log Lat.	1.69650	log. Dep.	1.47527
Lat.	49.72	Dep.	29.87

In this work, if the characteristic exceeds 10 drop off 10, as was done in this example.

PARALLEL SAILING

To change the number of miles of Dep. (E or W) into the corresponding number of minutes of longitude (D. Lo.) we may use the traverse table or we may use logs. The D. Lo. is found by multiplying the Dep. by the secant of the latitude,* and since this is exactly what we would do if we were solving a right triangle like that in Fig. 32, we may use Table 2 for this purpose, since Table 2 gives us the parts of the triangle all worked out. In doing this we must call our Dep. the *Lat.*, and call our D. Lo. the *Dist.*, and call our Latitude the *Course*. This is illustrated in Fig. 34. Then from Table 2 we may find the D. Lo. by the following rule:

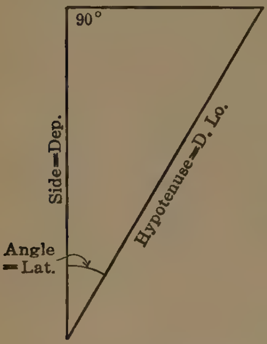

FIG. 34. D. Lo. by Traverse Table.

Enter the traverse table with the degrees of the latitude at the top, or bottom, of the page and find the Dep. in a column marked "Lat." The distance opposite

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* The reason we have to multiply by the secant of the latitude is that the lengths of the minutes on the parallel and on the equator have the same relation to each other as the radius of the parallel and the radius of the equator, and these have the same relation as unity and the secant of the latitude. Since the minutes of the parallel are smaller their number will be greater than the number of miles in the proportion of the secant of the latitude to unity.

this Dep. is the number of minutes in the D. Lo. If the degrees are at the top of the page, use the names Lat. and Dep. at the top; if the degrees are at the foot of the page use the names Lat. and Dep. at the foot of the page.

Example. A vessel in latitude 50° N, longitude 30° W, sails 60 miles due west. In what longitude is she? On the page (Table 2) marked 50° at the bottom we find in a Lat. column 59.8 (the nearest number to 60). Opposite to this in the distance column is 93 (or 1° 33′), which is the D. Lo. To find the D. Lo. more exactly we notice that 60 is two sixths the way from the number opposite 93 to the number opposite 94, so that $93\frac{1}{3}$, or 1° 33′.3 W, is the D. Lo. corresponding to 60 miles Dep. Adding this D. Lo. to the Long. 30° W, we find that the ship is in Long. 31° 33′.3 W.

To find the D. Lo. by logs add the log Dep. to the log secant of the latitude. The sum is the log D. Lo. The log secant is found from Table 44 exactly as for a log sin. If the preceding example is worked out by this method we should have

log Dep. (60)	1.77815
log. sec. 50°	0.19193
log. D. Lo.	1.97008
D. Lo.	93.34

which agrees closely with the previous result.

MIDDLE LATITUDE SAILING

If, however, the course is not exactly E or W the vessel will change her latitude. In this case it would not be correct to use the Lat. from which the vessel started nor the Lat. arrived at, because the number of minutes of D. Lo. is different in different latitudes. So we use the *middle latitude* when taking out the D. Lo. from the traverse tables. This will be accurate for all ordinary distances such as can be run in a day.

Rules for Middle Latitude Sailing

First find the D. Lat. and Dep. from the traverse table as usual.

Find the *Lat. in* as follows: if the Lat. left and the D. Lat. are of the same name (both N or both S) add them and give the sum the same name; if the Lat. left and the D. Lat. are of different names take the difference and give the result the name of the greater.

Next find the Mid. Lat. by taking the half sum of the *Lat. left* and *Lat. in.*

Then enter Table 2 with the degrees of the Mid. Lat. at the top (or bottom) of the page and find the Dep. in a column marked "Lat." The Dist. opposite this Dep. is the number of minutes in the D. Lo. If the degrees are at the top of the page use the names Lat. and Dep. at the top; if the degrees are at the foot of the page use the names Lat. and Dep. at the foot of the page.

To find the *Long. in*: if the Long. left and D. Long. are of the same name (both E or both W) add them

and give the sum the same name; if the Long. left and D. Lo. are of different names take the difference and give the result the name of the greater.

Example. If a vessel sails S 30° W, 200 miles, starting in Lat. 45° N, Long. 60° W, we find for the D. Lat. 173.2 and for the Dep. 100. We first find the new Lat. (called *Lat. in*) as follows:

Lat. left	45° 00′	N
D. Lat.	2 53.2	S
Lat. in	42° 06′.8	N

To look up the D. Lo. we need the **middle** Lat. which is found as follows:

Lat. left	45° 00′	N
Lat. in	42 06 .8	N
Sum	2)87° 06′.8	
½ sum = Mid. Lat.	43° 33′.4	N

With middle Lat. 44° as a "Course" and with Dep. 100 as a "Lat." we find in Table 2 as "Dist." 139 (= 2° 19′) which is the D. Lo. If we used 43° for the Mid. Lat. we should obtain 136.7 for the D. Lo. The true D. Lo. is somewhere between, about half-way from 139 to 136.7, or nearly 138. The *Long. in* is then found as follows:

Long. left	60° 00′	W
D. Lo.	2 18	W
Long. in	62° 18′	W

If it is desired to work the middle latitude rule by logs proceed as follows:

Find the Lat. and Dep. as explained on p. 83.

Find the Lat. in and the Mid. Lat. as explained in the rule on p. 88 (Mid. Lat. rule).

Then add the log Dep. to the log secant Mid. Lat.; the result is the log D. Lo.

Find the Long. in as explained on p. 88. (For use of logarithms see pp. 83 to 85.)

Example. Using the same example as given on p. 89 we first find the Lat. and Dep.:

log Dist.	2.30103	log Dist.	2.30103
log cos. 30°	9.93753	log sin. 30°	9.69897
log Lat.	2.23856	log Dep.	2.00000
D. Lat.	173.2 S	Dep.	100.0 W

Then the Lat. in and the Long. in are found as follows:

Lat. left	45° 00′ N
D. Lat.	2 53.2 S
Lat. in	42° 06′.8 N
Mid. Lat.	43° 33′.4 N

log Dep. = 2.00000

log sec. Mid Lat. = 0.13985

log D. Lo.	2.13985
D. Lo.	138.0

Long. left	60° 00′ W
D. Lo.	2 18.0 W
Long. in	62° 18′.0 W

Middle Latitude sailing should not be used if the track crosses the equator.

TRAVERSE SAILING

If a vessel sails several courses, as when tacking, this zig-zag track is called a *traverse.* Traverse sailing consists in finding the distance made good to the N or S and the distance made good to the E or W, and reducing the whole traverse to a single course and distance which would carry the vessel from the first point to the last point (Fig. 35). To find the change in her latitude and longitude take out from the traverse tables the Lat. and Dep. for each (true) course, writing each number in its proper column in a table ruled as in the following example. If the course is NE, for instance, put the Lat. in the N column and the Dep. in the E column. Take the sums of each of the four columns. Take the difference between the N and S columns and also the difference between the E and W columns. Mark the difference in each case with the letter (or name) of the greater. The

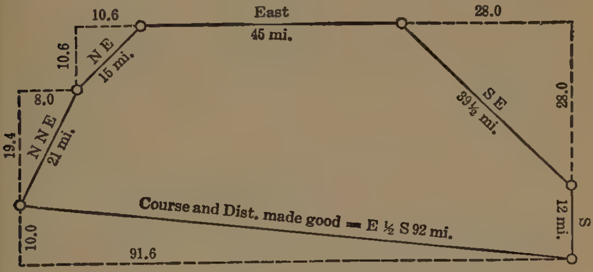

FIG. 35. Traverse.

difference between the N and S columns is the difference in latitude and may be applied at once to the Lat. left to find the Lat. in. If the D. Lat. is of the same name as the Lat. left it should be added; if of different name it should be subtracted.

Before the new longitude can be found the difference in the departure columns must be changed into D. Lo., using the middle Lat. for this purpose, by the rule given on p. 88. The D. Lo. is then added to or subtracted from the Long. left according to whether they are of the same or of different names. To find the course and distance made good (that is, the course and distance equivalent to the entire traverse) look in the traverse table for a Lat. and a Dep. which are abreast of each other on the same page and equal to the Lat. and Dep. made good. It will not usually be possible to find these exactly, so take the Lat. and Dep. that come the nearest. The course at the top or bottom of the page and the Dist. abreast the Lat. and Dep. are the course and distance required. If the Lat. is greater than the Dep. look for the course at the top of the page; if the Lat. is less than the Dep. look for the course at the bottom of the page.

Since there are four different courses at the top and bottom of each page it will be necessary to determine from the names of the D. Lat. and the Dep. in which of the four quadrants the course lies. For example, if the D. Lat. is N and the Dep. is E, the course will be between 0° and 90°; if the D. Lat. is S and the Dep. is E the course is between 90° and 180°, etc.

Example. A ship in Lat. 51° 10′ N, Long. 40° 19′ W, sails NNE, 21 mi., NE, 15 mi., E, 45 mi., SE, 39.5 mi., S, 12 mi. What is her position by dead reckoning (D. R.) and what are the course and distance made good?

True Course	Dist. (miles)	D. Lat. N	D. Lat. S	Dep. E	Dep. W	D. Lo.
NNE........	21	19.4		8.0		
NE..........	15	10.6		10.6		
E............	45			45.0		
SE..........	39.5		28.0	28.0		
S............	12		12.0			
		30.0	40.0	91.6		145½′ =
			30.0			2° 25′.5
			10.0			

Lat. left	51° 10′ N	Long. left	40° 19′ W
D. Lat.	10 S	D. Lo.	2 25.5 E
Lat. in	51° 00′ N	Long. in	37° 53′.5 W

Course and distance made good E ½ S, 92 miles.

In taking out the Lat. and Dep. for 39.5 mi. we may take the Lats. and Deps. for 39 and for 40 and divide the sum by two; or we may take out the Lat. and Dep. for 39 and then for 0.5 mi. and add them. To find the Lat. and Dep. for 0.5 mi. take out the numbers for 5 mi. and point off, one place to the left.

The Dep. for the E course and the Lat. for the S course are not in the traverse table because the right triangle becomes a straight line and no calculation is necessary.

When sailing East or West the Dep. is the same as the Dist. When sailing North or South the Lat. is the same as the Dist.

If it is desired to find by logs the Course and distance made good, subtract the log Lat. from the log Dep.; the result is log tan Course. Find the Course in Table 44; at the same time take out the log cosec Course. To find the log dist. add log Dep. to log cosec Course, and look up the Dist. in Table 42. If the Course is much less than 45° (nearly N or S) it will be better to find the log Dist. by adding the log Lat. to the log secant Course.

Example. Suppose that the Lat. is 42.1 N and the Dep. is 86.0 E.

$$\begin{aligned} \log \text{Dep.} &= 1.93450 \\ \log \text{Lat.} &= \underline{1.62428} \\ \log \tan C &= 0.31022 \\ C &= 63^\circ\ 55' \end{aligned}$$

The course is therefore 63° 55′ or N 63° 55′ E.

$$\begin{aligned} \log \text{Dep.} &= 1.93450 \\ \log \operatorname{cosec} C &= \underline{0.04665} \\ \log \text{Dist.} &= 1.98115 \\ \text{Dist.} &= 95.75 \end{aligned}$$

THE DEPARTURE COURSE

When starting on a voyage it is necessary to start the traverse from some definite point of known latitude and longitude. If the vessel passes near a lighthouse the bearing can be taken and the distance estimated. This would not be very accurate, however, and a much better result will be obtained by taking two bearings of the light and the distance run between them. Or, a position can be found by means of cross bearings (p. 66). When the bearing and distance to the object have been found this line may be made the first line of the traverse by *reversing* the bearing, and then including the line in the courses and distances run. The bearing used should of course be *true*, that is, corrected for variation and deviation. The reversed bearing to the light is usually called the *departure course.* The reading of the log and the corresponding time should be taken at this point.

Example. By means of cross bearings it is found that Minots Ledge Lighthouse is 3½ miles away and that its compass bearing is 160° (ship's heading being 95°). The deviation is 5° E; variation 14° W. The course is then set at 95°; run 91 miles. Course is then changed to 97°, deviation 5° E, variation 16° W; Dist., 56 miles. The traverse is then worked out and the Lat. in and Long. in are found as follows:

TRAVERSE INCLUDING THE DEPARTURE COURSE

Compass Course	Var.	Dev.	Error	True Course	Dist.	N. Lat.	S. Lat.	E. Dep.	W. Dep.	D. Lo.
340°*	14°W	5°E	9°W	331°	3½	3.1	....	....	1.7	...
95°	14°W	5°E	9°W	86°	91	6.3	....	90.8	....	...
97°	16°W	5°E	11°W	86°	56	3.9	....	55.9	....	...
						13.3 N		146.7 E 1.7 W 145.0 E		196.3

* Departure course.

Lat. Minots	42° 16′ 11″ N	Long. Minots	70° 45′ 35″ W
D. Lat.	13 18 N	D. Lo.	3 16 18 E
Lat. in	42° 29′ 29″ N	Long. in	67° 29′ 17″ W
Mid. Lat.	42° 22′ 50″ N		

CURRENT

Whenever there is a current of known set and drift this should be included as one line of the traverse, because the ship is carried over this course and distance by the water just as though she sailed it as one of her courses. The courses and distances shown by the compass and log give her movement with reference to the water, but the movement of the water itself has carried her over the course and distance given by the set and drift of the current.

Example. Suppose that a vessel in Lat. 32° 00′ N, Long. 78° 00′ W, sails due East (true) 20 miles in 2 hours, and is in a current which sets NE (true) 2 miles per hour. The traverse for finding her change in Lat. and Long. would be as follows:

Course	Dist.	N	S	E	W	D. Lo.
East.....	20	....	....	20.0	....	....
NE......	4	2.8	....	2.8	....	....
		2.8		22.8		26.9

Lat. left	32° 00′ N	Long. left	78° 00′ W
D. Lat.	2.8 N	D. Lo.	26.9 E
Lat. in	32° 02′.8 N	Long. in	77° 33′.1 W

If it is desired to make allowance for current so as to make good a certain course and distance we may reverse the set of the current and treat it as a course to be sailed, the drift of the current being the corresponding distance.

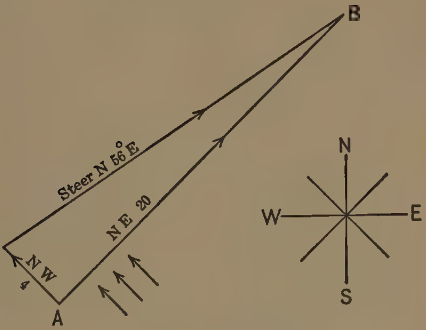

Fig. 36. Current.

Suppose, for example, that a vessel is to go to a point that bears N 45° E, 20 miles distant, and that she will be in a current which sets N 45° W, drift 4 miles (Fig. 36). Reversing the set of the current we have the following traverse.

Course	Dist.	Lat.		Dep.	
		N	S	E	W
S 45° E......	4	....	2.8	2.8	....
N 45° E.....	20	14.1	....	14.1	....
		14.1	2.8	16.9	

2.8

11.3

In traverse tables for Lat. 11.3 N and Dep. 16.9 E we find the course 56°. The true course to steer is therefore N 56° E in order to make good the course N 45° E.

CROSSING THE 0° (GREENWICH) MERIDIAN

If the traverse crosses the 0° meridian the D. Lo. will be greater than the Long. left. In this case take the difference between the Long. left and the D. Lo. and mark the difference with the name of the D. Lo. For example, if the Long. left is 1° 20′ W and the D. Lo. is 2° 05′ E then the Long. in is 0° 45′ E.

CROSSING THE 180° MERIDIAN

In this case if we should proceed as usual we would come out with a longitude greater than 180°. When this occurs take the result from 360° and mark it with the contrary name. For example, if the Long. left is 179° 30′ W and the D. Lo. is 2° 10′ W, the Long. in comes out 181° 40′ W. Since this is over 180° take it from 360° and call it East; the Long. in is therefore 178° 20′ E.

PROBLEMS

1. A vessel in latitude 36° 30′ N sails west 156.5 knots (nautical miles). Her longitude left was 60° 19′ W. What is the longitude in? *Ans.* 63° 34′ W.

2. A vessel in Lat. 61° N, Long. 30° W sails west 96 miles. What is the longitude in? *Ans.* 33° 18′ W.

3. A vessel in Lat. 40° N, Long. 30° W sails S 45° W 400 miles. What is her longitude? *Ans.* 35° 59′ W.

4. A vessel in Lat. 50° S, Long. 10° W sails SSW 290 miles. What is her longitude? *Ans.* 13° 01′ W.

5. A vessel in Lat. 39° 51′ N, Long. 49° 16′ W sails the following courses: S 45° E, 14 mi., S 72° E, 20 mi., N 68° E, 18 mi., N 76° E, 21 mi., N 89° E, 61 mi. Find Lat. and Long. in, and course and distance made good. *Ans.* 39° 48′ N, 46° 30′ W, S 89° E, 127 mi.

6. A vessel in Lat. 46° 18′ N, Long. 31° 10′ W, sails NE 21 mi., ENE 8 mi., E by S 18 mi., S by E ½ E 12

mi., SSW 14 mi. Find Lat. and Long. in and course and distance made good.

Ans. 46° 08′ N, 30° 15′ W, ESE $\frac{3}{4}$ E, 39 miles.

7. A vessel in Lat. 42° 00′ N, Long. 60° 00′ W, sails SE by S 29 mi., NNE 10 mi., ESE 50 mi., ENE 50 mi. Find her position and the course and distance made good.

Ans. 41° 45′.1 N, 57° 29′.3 W, E $\frac{3}{4}$ S, 113.7 mi.

8. By doubling the angle on the bow a vessel is located from a lighthouse. The true bearing of the lighthouse is S 39° W; its distance is 2.1 miles. The heading is S 20° E, true, and she runs on this course 2.5 miles. Course is then changed to S 66° E, true, run 28.0 miles; then N 42° E, true, run 30.0 miles. The position of the lighthouse is Lat. 44° 34′.1 N, Long. 67° 22′.0 W. Find her Lat. in and Long. in.

Ans. 44° 44′ N, 66° 15′ W.

9. As a vessel is passing Monhegan I. lighthouse the compass bearing is 333°, var. 18° W, dev. 1° E, distance 3 miles; position of light, Lat. 43° 46′ N, Long. 69° 19′ W; ship's heading changed to 238° by compass, var. 17° W, dev. 1° W, run 87 miles. Course is then changed to 249° by compass, var. 16° W, dev. 1° W, run 21 miles. Find her Lat. in and Long. in. Also find course and distance made good from the light.

Ans. 221°, 108 mi.; 42° 24′ N, 70° 55′ W.

10. At noon, Lat. 48° 16′ N, Long. 30° 10′ W, a vessel's log reads 20.1 mi. The course is 165° by compass, error 5° E. At 1 P.M. log reads 38.6 mi. Course 160° (p.c.),

error 6° E. At 3 P.M. log reads 74.0. Course 158°, error 6° E. At 4.30 P.M. log reads 85.6. Find the position by D.R. (dead reckoning) at $4^h\ 30^m$.

Ans. 47° 12′ N, 31° 50′ W.

11. A vessel in Lat. 40° 00′ N, Long. 71° 00′ W runs, by compass, 170°, var. 11° W, dev. 5° E, 40 mi.; 210° (by compass), var. 10° W, dev. 3° W, 20 mi.; 250° (by compass), var. 9° W, dev. 1° W, 13 mi.; 271° (by compass), var. 9° W, dev. 3° E, 26 mi. Find position by D.R. and course and distance made good.

Ans. 38° 53′.6 N, 71° 41′ W, 206°, 74 mi.

12. A vessel in Lat. 40° 10′ N, Long. 35° 50′ W sails the following courses by compass:

Course	Variation	Deviation	Leeway	Tack	Distance, miles
40°	24° W	5° E	5°	Port	21
100°	24° W	1° W	3°	Starboard	17
190°	24° W	4° E	8°	Starboard	41
300°	24° W	3° W	3°	Port	29

Find position by D.R. (dead reckoning).

Ans. 39° 56′ N, 35° 37′ W.

13. A vessel in Lat. 39° 51′ N, Long. 49° 16′ W runs 157° (p.c.), var. 22° W, dev. 3° E, wind 3°, 14 mi.; 128°, var. 22° W, dev. 4° E, wind 2°, Dist. 20 mi.; 91°, var. 22° W, dev. 1° W, wind 0°, Dist. 18 mi.; 99°, var. 22° W, dev. 1° W, wind 0°, Dist. 21 mi.; 110°, var.

22° W, dev. 2° E, wind 1°, Dist. 61 mi. The wind is west, by compass. Find position by D.R.

Ans. 39° 48′ N, 46° 31′ W.

14. A vessel sails N 30° W 42 mi., N 51° W 50 mi., due west 12 mi. During this time she was in a current which set N 60° E, 8 miles. What is her course and distance made good? *Ans.* N 42° W, 97 mi.

15. At 6^h A.M. Minots Ledge Light is 4 points off the starboard bow; log reads 90.0 mi. At $6^h\ 06^m$ A.M. Minots is abeam, bearing SSW by compass; patent log reads 92.1 mi. At $6^h\ 06^m$ A.M. course is set at ESE by compass, var. 13° W, dev. ¼ pt. E; on this course ship runs 43 miles. At $8^h\ 20^m$ course is changed to S 30° E, var. 14° W, dev. 1° E, run 20 miles. At $9^h\ 20^m$ course is set at S 15° W, var. 14° W, dev. 1° W, run 47 miles, to noon. At noon course is set at 210°, var. 12° W, dev. 1° W, run 150 miles. At 7 P.M. course is changed to 212°, var. 9° W, dev. 2° W, run 200 miles to 8 A.M. Find the Lat. and Long. by D.R. at noon and also at 8 A.M. The position of Minots is Lat. 42° 16′ 11″ N, Long. 70° 45′ 35″ W.

Ans. Noon $\begin{cases} 41° 08' \text{ N} \\ 69° 30' \text{ W} \end{cases}$ 8 A.M. $\begin{cases} 35° 38' \text{ N} \\ 71° 58' \text{ W} \end{cases}$

LAYING OUT A COURSE

If the distance to be run is not very great (say 400 miles), and especially if the course is nearly east or west, we may employ middle latitude sailing for laying out a course. For long distances and in high latitudes, especially with courses running more nearly north and south, Mercator sailing should be used. Whenever the Mercator track is considerably longer than the great-circle track between the points of departure and destination, great-circle sailing may be used to save distance.

MIDDLE LATITUDE SAILING

Suppose that we wish to know the course and distance to sail from a point in Lat. 30° 20′ N, Long. 71° 25′ W to a point in Lat. 32° 20′ N, Long. 65° 10′ W.

Take the difference of latitudes and the difference of longitudes; then turn the D. Lo. into Dep. by reversing the rule previously given, that is, on the page of Table 2 containing the degrees of the middle latitude look for the D. Lo. in a Dist. column; the number abreast of this in the Lat. column is the Dep. sought. To find the true course and distance to sail look in Table 2 (or Table 1, if desired) and find this D. Lat. and Dep. on the same line. The course and distance corresponding are the ones required.

The true course must be converted into a compass course by applying the variation and deviation. Our example would then be worked out as shown on p. 104.

MIDDLE LATITUDE SAILING

Departure*	30° 20′ N		71° 25′ W
Destination	32° 20′ N		65° 10′ W
D. Lat. =	2° 00′ N	D. Lo. =	6° 15′ E
=	120′	=	375′ = 321.4 mi. Dep.
Mid Lat. =	31° 20′		
(true) Course =	N 70° E	Dist. =	342 mi.
=	70°		

---

[*] The word departure is used here to denote the position left; it should not be confused with Dep., the distance east or west.

If the distance is great the traverse tables will not be accurate or convenient, and it is better to use logarithms.

To find the log. Dep. add the log. D. Lo. (Table 42) to the log. cos Mid. Lat. (Table 44). To find the course (*C*) subtract log D. Lat. (Table 42) from log Dep. The result is log tan *C*. The course is then found in Table 44. The degrees and minutes corresponding to the nearest log tan will be the required course.

To find the distance add log cosec *C* to log Dep. The dist. is the corresponding number in Table 42. (For the use of logarithms see p. 83.)

Example. Lat. left, 42° 20′ N, Long. left, 70° 45′ W; Lat. dest., 43° 00′ N, Long. dest., 50° 00′ W. Find course and distance.

$$\begin{aligned} \text{D. Lo.} &= 20^\circ\,45' = 1245' \\ \text{middle Lat.} &= 42^\circ\,40' \\ \text{D. Lat.} &= 40' \end{aligned}$$

$$\begin{aligned} \log \text{D. Lo.} &= 3.09517 \\ \log \cos \text{Mid. Lat.} &= \underline{9.86647} \\ \log \text{Dep.} &= 2.96164 \\ \log \text{D. Lat.} &= \underline{1.60206} \\ \log \tan C &= 1.35958 \\ C &= (\text{N})\ 87^\circ\,30'\ (\text{E}) \end{aligned}$$

$$\begin{aligned} \log \text{Dep.} &= 2.96164 \\ \log \csc C &= \underline{0.00041} \\ \log \text{Dist.} &= 2.96205 \\ \text{Dist.} &= 916'.3 \end{aligned}$$

After we have found the angle between the track and the meridian (between 0° and 90°) we may write it as a course in the 360° system, because we know which quadrant the course is in. For example, if the angle (*C*) found in the table is 30°, and the course is between N and W, it is written 330°.

Middle Latitude sailing should not be used if the track crosses the equator.

MERCATOR SAILING

The lengths of the degrees of latitude on Mercator's chart are increased according to the latitudes. The number of miles in these increased latitudes is given in Bowditch, Table 3. These are called "meridional parts." Problems in Mercator sailing that can be worked out by chart may be solved still more accurately by the use of this table. There are two cases that arise under Mercator sailing.

(1) Given the Lat. left and Long. left and the course and distance sailed, to find the Lat. and Long. in. In this case the new Lat. may be found by the ordinary method, using the traverse tables, or logs.

Having found the new latitude, take from Table 3 the meridional parts for the two Lats. If the Lats. are in the same hemisphere (both N or both S) subtract the less from the greater. Call this difference *m*. To find the log D. Lo. add log *m* to log tan *C*.

(If the two lats. are in opposite hemispheres take the sum of the meridional parts and call it *m*.)

The following diagram (Fig. 37) will make clearer the relation between the different numbers. The D. Lo.

bears the same relation to *m* as the Dep. bears to the D. Lat. The reasons for all the rules of Mercator sailing may be understood by inspecting the diagram, which consists of two right triangles.

Example. Lat. left, 40° 00′ N, Long. left, 31° 00′ W. Course S 31° W, Dist. 660 mi.

	Lat. left	40° 00′ N	Mer. Pts.	2607.6
By Table 2	D. Lat.	9° 25 .8 S		1915.8
	Lat. in	30° 34′.2 N	*m*	691.8
	Lo. left	31° 00′ W	log *m*	2.83998
	D. Lo.	6 55 .7 W	log tan *C*	9.77877
	Lo. in	37° 55′.7 W		2.61875
			D. Lo. =	415′.7
		(Table 42)		
				= 6° 55′.7

In taking out the meridional part for 30° 34′.2 it is sufficiently accurate to take the nearest whole minute. If it were needed with greater accuracy we should add to 1915.8 a correction equal to two tenths of the difference between 1915.8 and 1917.0, that is 0.2 × 1.2 = 0.24, giving 1915.8 plus 0.2 = 1916.0.

(2) The second case arising under Mercator sailing is when the Lat. and Long. of the point of Departure and the Lat. and Long. of the Destination are given, and the course and distance are to be found.

In this case take the difference of the latitudes, the difference of the longitudes, and the difference of the meridional parts (*m*), if both lats. are N, or both are S. Subtract the log of *m* from the log D. Lo. (Table 42). The result is the log tan *C*;

find the course (*C*) from Table 44 as described on pp. 85 and 105, then add the log secant *C* to the log D. Lat. and the result is the log of the distance.

If the Lats. are in opposite hemispheres take the sum of the meridional parts and call it *m*. Take out log sec *C* while you have the page open from which you find *C*. Sec *C* will be on the same line as tan *C*, already found. This will be made clearer by an example.

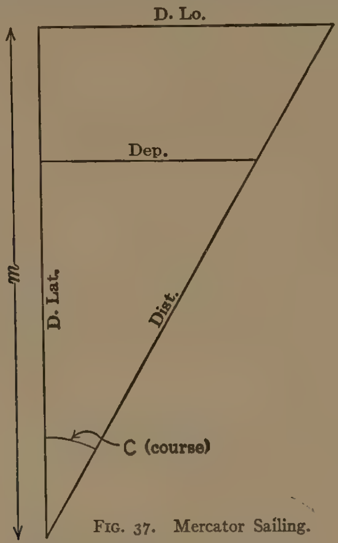

FIG. 37. Mercator Sailing.

Example. Find the course and distance from a point in Lat. 47° 30′ N, Long. 52° 45′ W to a point in Lat. 35° 57′ N, Long. 5° 45′ W. (See next page.)

MERCATOR SAILING

Lat. left	47° 30′ N
Lat. of Dest.	35 57 N
D. Lat. =	11° 33′
=	693′

Mer. pts.	3229.6
(Table 3)	2300.5
m =	929.1

Long. left	52° 45′
Long. of Dest.	5 45
D. Lo. =	47° 00′
=	2820′

log D. Lo.	3.45025
log m	2.96806
log tan C	0.48219
(true) Course =	S 71° 46′ E
=	108° 14′

log D. Lat.	2.84073
log sec C	0.50457
log dist.	3.34530
Dist. =	2215 miles

PROBLEMS

1. Find the course and distance from 40° 40′ N, Long. 51° 35′ W to 50° 50′ N, 10° 55′ W.

Ans. Course N 70° 16′ E, 1807 mi.

2. Find the course and dist. from 13° 10′ N, 59° 30′ W to 36° 00′ N, 5° 33′ W.

Ans. Course N 64° 57′ E, 3236 mi.

3. Find course and dist. from 56° 40′ N, 59° 00′ W, to 51° 00′ N, 10° 00′ W.

Ans. S 78° 55′ E, 1769 mi.

4. Find course and distance from 55° 15′ N, 59° 00′ W, to 37° 00′ N, 8° 55′ W.

Ans. S 62° 01′ E, 2334 mi.

GREAT-CIRCLE SAILING

In sailing over a great-circle track, in order to make the shortest distance between two points, we need to know the course at each point along the track and also the total distance to be run. In solving this problem we have a choice of three different ways.

First, we may draw a straight line on the great-circle chart between the two points, and transfer points on this line to the Mercator Chart. To do this take off the latitudes of the points where the track crosses the meridians of the great-circle chart. Mark off these latitudes and longitudes on the Mercator chart and connect these points by straight lines. The courses and the distances between these points may be taken from the Mercator chart by use of the parallel rulers, compass rose, and dividers.

Second, we may find the (true) course at any point on the track by the use of the tables of the Sun's Azimuth (Hydrographic Office Publ. No. 71) or by the tables of Azimuths of Celestial Bodies (Hydr. Office Publ. No. 120) These tables are calculated to give the azimuth, or true bearing, of the sun or stars when the observer's Lat., the declination, and the time are known. But by changing the names we may use the same tables for finding the course to steer. If in H. O. No. 71 we call the Latitude of the point of departure the "*Lat.*" and call the Latitude of the point of destination the "*Sun's Decl.*," and call the D. Lo. the "*Apparent time*," then the corresponding azimuth of the sun will be the same as the initial course to steer along the great-circle track. If the Lat. of Dest. is greater than 23° it will be convenient to use H. O. No. 120. In this table look up the D. Lo. as an "Hour angle" (instead of "apparent time"); otherwise it is arranged exactly the same as No. 71. One advantage of this method is that the course to steer may be looked up in the table whenever the course is to be changed, each day or at each watch, and no calculation is necessary. If the final course is desired it may be found by simply interchanging the Lat. and Decl. in the tables and looking up the course again. (See p. 191 for the use of these tables.)

The length of the track may be found by the sine rule:

Add the log sin D. Lo., log cos Lat. (of the point of departure) and log cosec of the final course. The sum is the log sin Dist.

This dist. will be found in Table 44 as degrees and minutes and must be changed to minutes to get the dist. in nautical miles. If the distance is large, say about 5400 miles, there might be a doubt whether the true distance is the acute angle or the difference between this angle and 180°. In this case the Haversine rule given below is better.

Third, we may calculate the distance by the Haversine rule, and then find the course by the sines. The rule for distance is as follows:

Add together the log hav. D. Lo, log cos Lat. of point of departure and log cos Lat. of dest. Call this the log hav. θ. Find natural hav. θ and add it to nat. hav. of the difference of the two Lats.[*] The result is the nat. hav. Dist.

Example. Find the initial course, final course, and distance from Lat. 55° 18′ N, Long. 59° 00′ W to Lat. 51° 00′ N, Lo. 10° 00′ W.

From H. O. Publ. 120, using Lat. 55° 18′ N, Decl. 51° 00′ N (Lat. of Dest.), and Hour Angle $3^h\ 16^m$ (= 49° = D. Lo.),[†] we find for the Az., N 77° 48′ E which is the course at the start. Using Lat. 51°, Decl. 55° 18′, and Hour Angle $3^h\ 16^m$, the final course is S 62° 09′ E. The distance is then found as follows:

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[*] If one Lat. is N. and one Lat. S. take the sum.

[†] See page 132 for method of changing degrees into hours.

D. Lo.	49° 00′	log sin	9.87778
Lat.	55° 18′	log cos	9.75533
Final *C*	62° 09′	log csc	0.05346
		log sin Dist.	9.68657

Dist. 29° 04½′ = 1744½ miles

If the number of degrees in the final course is less than the number of degrees in the initial course it will be a little more accurate to take the cos Lat. left and cosec of initial course, and add these to the log sin D. Lo.

If it is desired to use the haversine formula we have:

D. Lo.	49° 00′		log hav.	9.23545
Lat. (dep.)	55° 18′ N		log cos	9.75533
Lat. (dest.)	51° 00′ N		log cos	9.79887
		θ	log hav.	8.78965
		θ	nat. hav.	.06161
Dif. Lats.	4° 18′		nat. hav.	.00141
Distance	29° 04½′		nat. hav.	.06302
Distance	1744½ miles			

To find the initial course, add the log. cos. Lat. of dest., log sin D. Lo., and log cosec Dist. The sum is log sin of initial course.

To find the final course, add the log cos Lat. (of dep.) log sin D. Lo., and log cosec Dist. The sum is the log sin of the final course.

log cos	51°	9.79887	log cos	55° 18′	9.75533
log sin	49°	9.87778	log sin	49°	9.87778
log cosec	29° 04½′	0.31340	log cosec	29° 04½′	0.31340
log sin *C*		9.99005	log sin *C*		9.94651
C		77° 47′	*C*		62° 09′

initial course N 77° 47′ E

final course S 62° 09′ E

Other formulas for finding these courses will be found on p. 297.

THE VERTEX

If the great-circle track is followed far enough a point will be reached where the course is exactly East or West; this is the point where the track is nearest to the pole and is called the *vertex*.

To find the Lat. and Long. of the vertex and the distance to the vertex:

> **Add log sin *C* (for initial course) and log cos Lat. left; the sum is log cos Lat. of vertex. Add log tan *C* to log sin Lat. left; the sum is log cot D. Lo. (from point of dep. to vertex). Add log cos *C* and log cot Lat. left; the sum is the log tan dist. (to vertex)**

Example. To find the Lat. and Long. of vertex in the example given on p. 112.

log sin *C*	9.99002
log cos Lat.	9.75533
log cos Lat.	9.74535
Lat. of *V*	56° 12′ N

log tan *C*	0.66391
log sin Lat.	9.91495
log cot D. Lo.	0.57886
D. Lo.	14° 46′

Long. left	59° 00′ W
D. Lo.	14 46 E
Long. of *V*	44° 14′ W

log cos *C*	9.32612
log cot Lat.	9.84038
log tan dist.	9.16650
Dist.	8° 21′
	= 501 miles to *V*

NOTES ON GREAT-CIRCLE SAILING

It will be noticed that when we sail from point to point on the great-circle track we are really sailing along chords (rhumb lines) of the track. When we take the course from H. O. No. 71 we are sailing on tangents to the track.

When the Lat. of Dest. is greater than 23° it is still possible to use H. O. No. 71 for finding the course, provided we have a great-circle chart. If the straight line through our point of Dep. and our point of Dest. on the great-circle chart is prolonged until it reaches a latitude which is less than 23°, then the course may be taken out for that Lat. and Long. as a destination; the course will be the same as it would if any other point on the same great circle had been selected. (Littlehales, H. O. No. 90.)

PROBLEMS

1. Find the initial and final courses and the length of a great-circle track from Lat. 13° N, Long. 59° W to Lat. 36° N, Long. 6° W.

Ans. N 54° 22′ E; N 78° 12′ E; dist. 3159 miles; change of course, about 1° for every 132 miles.

2. Find the initial and final courses and length of great-circle track from Lat. 40° 28′ N, Long. 73° 50′ W to Lat. 34° 21′ S, Long. 18° 29′ E.

Note. — The "difference in longitude" in this case is the sum of the east and the west longitudes.

Ans. S 63° 42′ E, S 55° 42′ E, 6783 mi.

CHAPTER VI

NAVIGATION BY OBSERVATION

Instruments used — Sextant

Navigation by observation consists in determining the position of the ship by measuring the altitude of the sun, moon or stars, and calculating the latitude and longitude. The altitude is the number of degrees, minutes and seconds that the center of the sun, moon or star is above the true horizon. This angle is found by means of the sextant.

The sextant is an instrument designed for measuring the angle between two visible objects; it is necessary therefore to measure the altitude of the sun or star above the sea-horizon instead of the true horizon.

The sextant (Fig. 38) consists of a frame carrying a graduated arc, or limb (*AB*), divided into degrees and usually ten-minute spaces. In some instruments the degrees are divided into 20-minute spaces, and in some into 30-minute spaces. The index-arm (*IE*) is pivoted at the center of the arc; at its lower extremity it carries a short arc marked with a vernier, *V*. The index, or 0-mark of this vernier, is the mark which shows on the arc the angle which has been measured. The index-arm may be clamped in any position by a screw (*C*) at the back and then may be moved slowly over small arcs by means of the tangent screw, or slow-motion screw (*T*). On the index-arm, over the pivot, is a mirror called the index-glass (*I*). At the front of the instrument is the horizon-glass (*H*), the right half of which is silvered; the left half is plain glass. Two sets of colored glass shades (*L*) and (*K*) are provided for making observations on the sun.

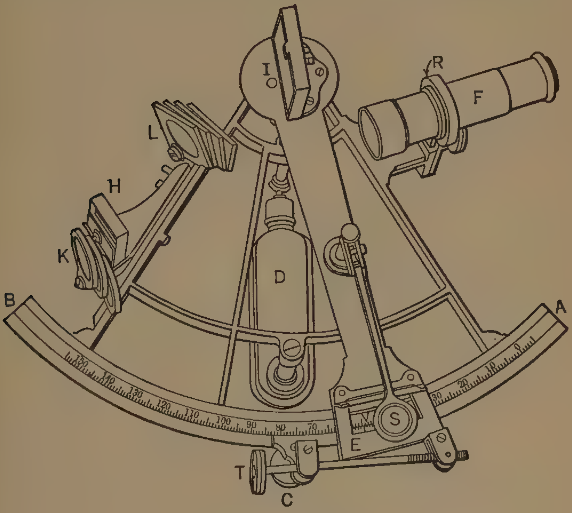

FIG. 38. The Sextant.

To measure an altitude of the sun move one of the colored shades (*L*) into line between the two mirrors, hold the instrument in the right hand, direct the line of sight (as shown by the telescope (*F*) and the horizon-glass) to that point of the horizon directly beneath the sun, move the index-arm out from 0°, away from the observer, until the reflected image of the sun is seen in the horizon-glass. Focus the telescope carefully. Set the index-arm so that the lower edge of the sun touches the horizon as shown in Fig. 39. This contact may be made perfect by setting the clamp tight, then moving the tangent screw until the edge of the disk just touches the horizon. The contact should now be tested by tipping the sextant to right and left in such a way as to cause the sun to swing in an arc, that is, it will move from side to side and will rise above the horizon on either side of the central position (Fig. 40). If it goes below the horizon at any point the angle is too great and the tangent screw should be moved, until the sun just touches the horizon at one point during the swing.

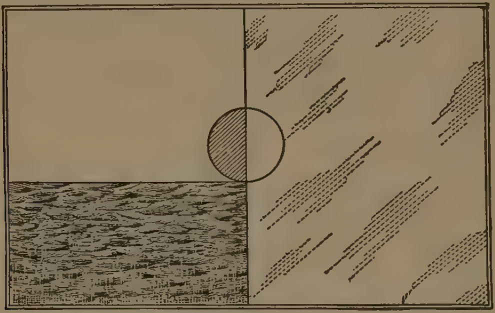

FIG. 39. Sun as seen in Sextant.

In sighting the sun it will be noticed that if the sextant is turned to the left so as to make the sun's image fall on the mirror, the sun's image is brighter but the horizon cannot be seen directly under it because it is obscured by the silver. If the sextant is turned to the right the sun can be seen reflected from the plain glass and at the same time the horizon can be seen under it. The angle will be more accurate if the contact is made when the sun is on the edge of the silvered portion, as shown in Fig. 39, which should be about in the center of the telescope.

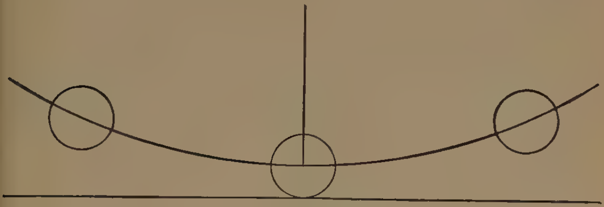

FIG. 40.

It is advisable for the beginner to take his first sights without any telescope because he can see better what he is doing. As soon as good sights can be taken in this manner the low power telescope should be used.

The altitude is next read from the arc by first noting the degrees and the ten-minute marks that have been passed over by the index-mark. Figure 41 shows the division of the arc into degrees and 10′ spaces, and Fig. 42 shows the appearance of the vernier and arc when the index is set to read 0°. When an altitude is taken the index-mark will usually be found to have passed a little beyond some mark on the arc. In Fig. 43 the index has moved over 2° 40′ and a little more.

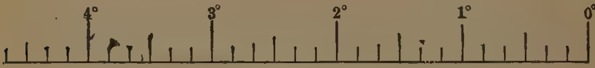

Fig. 41. Ten-minute Divisions of Arc.

To read this additional number of minutes beyond the 40′ mark, look along the vernier to the left and find the number of the graduation which is exactly in line with some graduation on the arc. The 10″ vernier has long lines for the minutes, shorter ones for the 30″ and still shorter lines for the remaining divisions. In Fig. 43, the 4′ 10″ line just coincides with a line on the arc and this is the amount to be added to the 2° 40′. The total altitude therefore consists of two parts, the reading of the arc and the reading of the vernier. These two

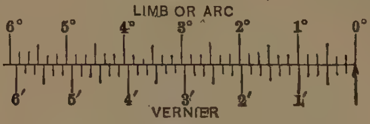

Fig. 42. Ten-second Vernier set at 0°.

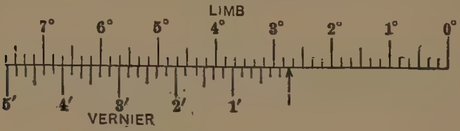

Fig. 43. Vernier Reading 2° 44′ 10″.

added together give 2° 44′ 10″, the observed altitude. This altitude must be corrected for Index Error, as explained later.

Other graduations and verniers are shown in Figs. 44, 45 and 46, the general method of taking the reading being the same as described above.

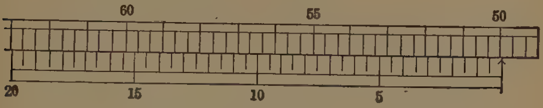

FIG. 44. Arc divided into 20′ spaces; vernier reading to 30″; actual reading 49° 57′ 30″.

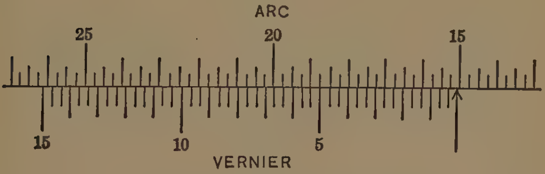

FIG. 45. Arc divided into 15′ spaces; vernier reading to 20″; actual reading 15° 05′ 00″.

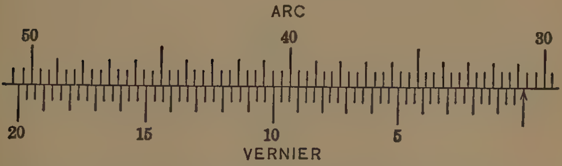

FIG. 46. Arc divided into 20′ spaces; vernier reading to 20″; actual reading 30° 49′ 40″.

ADJUSTMENTS OF THE SEXTANT

1. Set the index to read about 60° on the arc. Look in the index-glass and see if the reflected image of the arc appears to be an unbroken continuation of the actual arc. If there is a bend in the line it shows that the mirror is tipped forward or backward. By turning a screw in the back of the frame of this mirror it may be tilted until the line of the arc is continuous. This shows that the plane of the mirror is perpendicular to the plane of the graduated arc as it should be.

2. (*a*) Set the index to read about 0°. Place the telescope in position and sight toward a bright star; then by moving the index arm back and forth a little way find out whether the reflected image of the star passes directly over the direct image of the star, or whether it passes to one side. If the images coincide in one position the mirrors are parallel and the horizon-glass is adjusted; if the reflected image always passes to one side they are not parallel and the horizon-glass should be adjusted by means of the screw at the back.

This test may also be made by sighting on the sea horizon. First hold the sextant vertical, as when observing the sun, and set the reflected image of the horizon to coincide exactly with the horizon as seen directly. Then turn the sextant into a nearly horizontal position. If the images of the horizon do not now coincide the horizon-glass needs adjustment.

(*b*) With the index set at 0°, hold the sextant vertically, as when taking the sun, and examine the horizon.

If the horizon and its image do not coincide the proper adjusting screws should be moved until they do. If it is not desired to alter the adjustment, move the tangent screw until the images coincide. The reading of the index is then the *Index Correction* (I. C.), or the amount to be added to or subtracted from every reading of the sextant to obtain the correct angle. If the index is to the left of 0° the I. C. is marked − and is to be taken off every reading. If the index is to the right of 0° it is marked + and is added to the sextant reading to obtain the correct angle.* If the index is to the right of 0° the amount of the I. C. may be read in either of two ways.

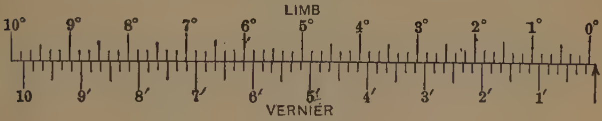

FIG. 47. Reading "Off the Arc."

(1) We may read the vernier as usual and then subtract from 10′, obtaining the amount by which the index has passed to the right of 0° or to the right of the last division it passed. (2) We may begin at the left end of the vernier and, disregarding the actual numbers, count off the minutes and 10″ spaces. In Fig. 47 the vernier reads 6′ 30″, but the I. C. is +3′ 30″. The index correction may be found still more accurately by observing the sun.

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* Or, according to the old rule, "When it's on it's off and when it's off it's on."

To find the index correction from the sun: Set the index near 0°; use colored shades in front of the horizon-glass as well as below the index-glass. Choose different colors for the two. Then look directly at the sun and bring the image of the sun's limb into contact with the limb as viewed directly (*a*, Fig. 48). Read the vernier. Then move the image across so as to be in contact at the opposite edge (*b*, Fig. 48). Read the vernier. The vernier reading which is off the arc (about 32′) should be marked +; the reading on the arc is marked −. Take the difference between the two readings, divide by 2, and mark the result with the sign of the greater reading. This gives the Index Correction.

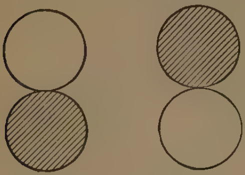
(*a*) (*b*)

FIG. 48. Index Correction by the Sun.

3. Sight over the plane of the instrument while it is resting on a table, and make a mark in this plane on a wall 20 ft. or more away. Allow for the height of the telescope above this plane. Sight through the telescope and see if this point comes in the center of the field of view. If not, tip the telescope by means of the adjusting screws until the marked point is in the center of the field of the telescope.

PROBLEM

The index correction is found by observation on the sun as follows: reading off the arc, 31′ 45″; reading on the arc, 31′ 25″. What is the I. C.? *Ans.* +10″.

THE CHRONOMETER

The longitude of the ship depends upon the Greenwich time, and this is shown by the chronometer carried on the ship. The chronometer is, for this reason, one of the most important of the instruments used, and great care should be exercised to see that it is kept running at a uniform rate. A second reason for carrying a chronometer is that in making his calculations the navigator must use the Nautical Almanac and this requires a knowledge of the Greenwich time.

The chronometer is an accurately made timepiece, hung in gimbals and set and regulated to keep solar time at the meridian of Greenwich (observatory), England. It is wound regularly once a day at some specified time. It should be kept in a special box, carefully protected from sudden changes of temperature, from magnetic influences, and from any jarring of the engines. The navigator should ascertain its error at some definite date and the daily rate at which it is gaining or losing, so that he may be able to calculate its error at any time it is required.

RATING THE CHRONOMETER

The sea-going rate of a chronometer is not usually the same as the rate determined when the chronometer is on shore. In order to find the sea-going rate the navigator should make a comparison with a standard clock or chronometer upon leaving a port and again upon arrival at another port, and then compute the daily rate during the voyage. If no comparison can be made in port he may make an observation on the sun at a place whose exact longitude he can obtain, and in this way find the true Greenwich Time and then the error of the chronometer. A comparison may be made every day at noon and at 10 P.M. by the radio time signals. The total gain or loss in time divided by the number of days elapsed gives the daily rate. If the chronometer is fast the correction is marked −, if slow it is +. When it is gaining the rate is marked −, if losing it is +.

Example. Suppose that at New York on Sept. 15 a chronometer is compared with a standard clock at a chronometer maker's shop at 1^h P.M. (Eastern Time), the clock having been corrected automatically by the Western Union clock. The corresponding time on the chronometer is $5^h\ 59^m\ 10^s$. Since 1^h P.M. Eastern Time is the same instant of time as 6^h P.M. at Greenwich the chronometer is 50^s slow, or its correction is $+50^s$. Again suppose that when the ship is south of C. Clear (Long. 9° 29′ 03″ W) the Greenwich Time is found by an observation* to be $3^h\ 56^m\ 27^s$ P.M. on Sept. 24, at which time the chronometer reads $3^h\ 55^m\ 47^s$. The correction is now $+40^s$.

$$\begin{array}{ll} \text{Sept. 15} & \text{C. C.} = +50^s \\ \underline{\text{Sept. 24}} & \underline{\text{C. C.} = +40} \\ \text{Diff. } 9^d & \text{gain} = \quad 10^s \end{array}$$

$$\text{Daily rate} = \frac{10^s}{9} = -1^s.1$$

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* For the method of taking the sight and finding the time at ship and the Greenwich Time, see Chapter IX.

COMPARISON OF CHRONOMETER AND WATCH

C – W

The chronometer should not be moved from its position. In order to take the time when sights are made an observing watch is often used. This watch is compared with the chronometer just before or just after the sight is taken. The error of the watch does not enter into the final result because we use the watch only for measuring the short interval between the observation and the comparison. The comparison is made as follows: Compare the chronometer and the watch and take the difference between the two. If the watch reading is less than the chronometer reading mark the difference +, if greater mark it –. This correction, called the C – W, is to be added to or subtracted from the watch time of sight to obtain the chronometer time of sight. In making this comparison it is not necessary to look at the chronometer at the instant; the ticks of the chronometer may be counted mentally while the eye follows the second-hand of the watch.

Example:

$$\begin{array}{rl} \text{Chro.} & 1^h\ 29^m\ 00^s \\ \text{Watch} & \underline{9^h\ 51^m\ 27^s} \\ C - W = & -8^h\ 22^m\ 27^s \end{array}$$

This time interval subtracted from the watch time of the sight will give the chronometer time of the sight.

If the observing watch is kept regulated to Greenwich Civil Time and its correction obtained frequently, it will be unnecessary to apply the C − W correction; the watch correction may be applied directly to the watch time.

On small vessels the time is often noted directly on the chronometer, a signal of some sort being used to notify an assistant when to take the time.

A stop watch is very convenient when a single observation is to be made.

HACK CHRONOMETER

When the ship carries several chronometers it is customary to use also a cheaper chronometer, called the "hack," which may be carried to any convenient place for use in observing, but is usually kept in the chart-house. The time of sights is not taken directly on the hack chronometer, but the observing watch is compared with the hack as already explained. The error of the hack on Greenwich Time is found by daily comparison with the other chronometers, the mean result for all the chronometers being taken as true Greenwich Time.

PROBLEM

Upon leaving Liverpool July 12 the error of the chronometer is found to be $1^m\ 32^s.3$ fast. On July 22 at Boston the time signal is heard at a telegraph station (12^h M. Eastern Time = 5^h P.M. Greenwich time); the chronometer is then $1^m\ 26^s.0$ fast. What is the daily rate? What are the corrections for Aug. 1, Aug. 2, Aug. 3?

Ans. $+0^s.63$; $-1^m\ 19^s.7$, $-1^m\ 19^s.1$, $-1^m\ 18^s.4$.

CHAPTER VII

MEASUREMENT OF TIME — THE NAUTICAL ALMANAC — CORRECTING THE ALTITUDE

MEASUREMENT OF TIME

It is important that the navigator should understand the different kinds of time employed in astronomical calculations, and the methods used in changing from one kind of time to another.

APPARENT AND MEAN SOLAR TIME

Apparent Solar Time is the time given by the sun, such as would be calculated from an observed altitude of the sun;* it is the kind of time given by the shadow cast on a sun dial. This kind of time, however, is not uniform throughout the year. That is to say, the days are not all of exactly the same length, because the rate of the sun's eastward motion in the sky is variable. For this reason a chronometer could not be regulated to this kind of time.

Mean solar time is an artificial time in which it is imagined that the sun's motion is uniform and the days, hours, minutes and seconds are always of the same length. The length of the mean solar day is the average of the lengths of the apparent solar days, so at the end of one year the two kinds of time come out the same. This is the kind of time kept by watches and chronometers. In both kinds of time the day is divided into 24 hours.

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* For the method of finding apparent time by observation see Chapter IX.

Sometimes the apparent time is ahead of the mean time, sometimes it is behind the mean time. The difference between the two at any instant is called the *Equation of time*, and may be found in the Nautical Almanac. This difference may amount to as much as 16 minutes of time.

CIVIL TIME

Civil Time is a name used to indicate the way in which we measure mean time or apparent time. For ordinary purposes we begin the day at midnight (0^h) and count up to noon (12^h); this half of the day is called A.M. Then we begin again at 0^h and count up to 12^h again at midnight; this second half of the day is called P.M. The date changes at midnight. For astronomical purposes the time is counted continuously from 0^h to 24^h, beginning at midnight, or the instant when the date changes. The hours which are ordinarily called P.M. will be greater than 12^h when expressed in this 24-hour system. For example, 6^h P.M., Jan. 1 = 18^h, Jan. 1. This is the kind of time used in the Nautical Almanac. Formerly *Astronomical* time was used in the Almanac, the 0^h being the instant of noon; the use of this kind of time has now been *discontinued*. But in consulting back numbers of the Almanac or editions of books previous to 1925 this fact must be borne in mind.

Most chronometers show but 12 hours on the dial, like ordinary watches; in this case it is necessary to add 12 hours to the actual chronometer reading if the Civil Time is P.M.

STANDARD TIME

Standard Time is a system of time used in the United States for convenience in Railroad transportation. It is based upon Greenwich Time. In the Eastern Time Belt the time is that of the 75° meridian (west), or 5^h slow of Greenwich; in the Central Time belt it is 6^h slow of Greenwich; in the Mountain Time belt it is 7^h slow of Greenwich; and in the Pacific Time belt it is 8^h slow of Greenwich.

On the H. O. chart No. 5192 will be found an explanation of the time zones for the whole world.

DAYLIGHT SAVING TIME

During the summer months some places adopt what is called *Daylight Saving Time.* This is simply the Civil Time of a belt one hour east of the one generally used. For example, if a district in the Central time belt uses Eastern Time during the summer it is called Daylight Saving Time for that district.

LONGITUDE AND TIME

Longitude is counted from the meridian of Greenwich (England), either to the east or to the west to the meridian of the ship, and is measured in degrees along the equator, as shown on the charts. It is also the angle at the pole between the two meridians. It may be expressed also in units of time, that is, in hours, minutes, and seconds. The earth turns through 360° in 24^h of time, or 15° for each hour of time. Consequently, the difference in longitude between any two meridians may be expressed either in degrees or in hours, min., and sec. difference in time.

> *To change degrees into hours:* **Divide the degrees by 15 and call the result hours; multiply the remainder by 4 and call it minutes. Then divide the minutes by 15, call the result minutes; multiply the remainder by 4 and call it seconds; divide the seconds by 15 and call the result seconds.**

Example. Change 116° 41′ 50″ into time.

$15\overline{)116^\circ}$

7^h and 11° remainder

$11^\circ \times 4 = 44^m$ $\qquad 7^h\ 44^m$

$15\overline{)41'}$

2^m and $11'$ remainder

$11' \times 4 = 44^s$ $\qquad 2^m\ 44^s$

$15\overline{)50''}$

$3^s\frac{1}{3}$ $\qquad 3^s\ \frac{1}{3}$

Result $\qquad \overline{7^h\ 46^m\ 47^s\ \frac{1}{3}}$

To change hours, min., and sec. into degrees, reverse the preceding process.

Example. Change $4^h\ 29^m\ 54^s$ into degrees, min., and sec.

$$
\begin{array}{rl}
4^h \times 15 = & 60^\circ \\
\dfrac{29^m}{4} = & 7^\circ \text{ and } 1^m \text{ remainder} \\
1^m = & 15' \\
\dfrac{54^s}{4} = & 13' \text{ and } 2^s \text{ remainder} \\
2^s \times 15 = & \underline{30''} \\
\text{Result} & 67^\circ\ 28'\ 30''
\end{array}
$$

These results may be found by means of Table 50, Bowditch. They may also be found conveniently by Table 45. But having once mastered the above process the change is made about as quickly without tables. It will be well to memorize the following.

$15^\circ = 1^h$

$15' = 1^m$

$15'' = 1^s$

$1^\circ = 4^m$

$1' = 4^s$

Care should be used in distinguishing the two kinds of minutes and seconds. Use the *m* and *s* for the min. and sec. of **time** only.

GREENWICH TIME AND LOCAL TIME

When the time is counted from the instant when the sun is on the meridian of Greenwich (at Greenwich midnight) the time is called *Greenwich Time.*

When the time is counted from the instant when the sun is on the meridian of any other place (say the ship's meridian) the time is called *Local Time* (Ship's Time).

RELATION BETWEEN GREENWICH TIME, LOCAL TIME AND LONGITUDE

The Longitude is the difference between Greenwich Time and the Time at Ship. When the Greenwich Time is greater than Local Time the Ship's Longitude is West; if Greenwich Time is less than the Local Time the Ship's Longitude is East. In Fig. 49 the Greenwich Civ. T. is A′AS; the Ship's Time is B′BS. The difference is A′B′ or AB, the west longitude.

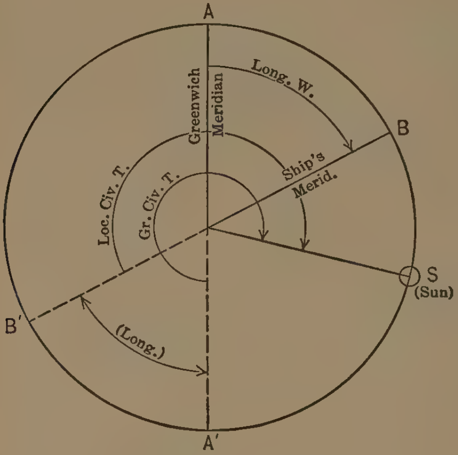


FIG. 49. Longitude and Time.

Example 1. The Greenwich Civil Time is $18^h\ 30^m$;

the longitude of the ship is 50° or $3^h\ 20^m$ West. What is the Time at Ship?

Greenwich Civil T.	$18^h\ 30^m$
Long. W	$3\ \ 20$
Civil Time at Ship	$15^h\ 10^m$ (i.e., $3^h\ 10^m$ P.M.)

Example 2. The Civil Time at Ship is $11^h\ 00^m$ the longitude is 60° or 4^h West. What is the Greenwich Civil Time?

Civil Time at Ship	$11^h\ 00^m$
Longitude West	$4\ \ 00$
Greenwich Civil Time	$15^h\ 00^m$ (i.e., 3^h P.M.)

Example 3. The Greenwich Civil Time is 5^h; the longitude of the ship is 45° or 3^h East. What is the Civil Time at Ship?

Greenwich Civil Time	$5^h\ 00^m$
Longitude East	$3\ \ 00$
Civil Time at Ship	$8^h\ 00$ (i.e., 8^h A.M.)

HOUR ANGLE

The Hour Angle of a body at any place is the angle at the pole (or the arc of the equator) included between the meridian of the place and the meridian through the body, counted from the observer's meridian westward from 0^h to 24^h (Fig. 50). For example, when it is 3^h P.M. the sun's hour angle is 3^h, or 45°. When it is 9^h A.M. the sun's hour angle is 21^h or 315°.

RIGHT ASCENSION

If we start at the vernal equinox and measure around the equator toward the east until we come to the meridian through a star we have measured the *Right Ascension* (R. A.) of that star.

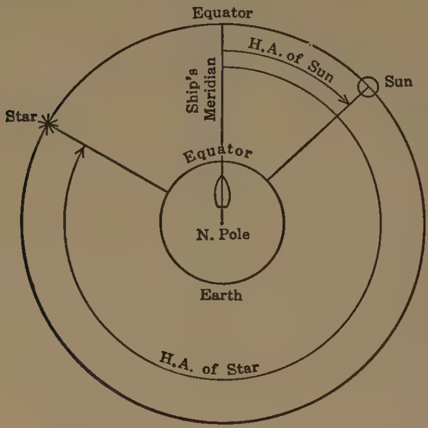


FIG. 50. Hour Angles.

LOCATING STARS

Right Ascension and Declination locate a star in the sky in just the same way that East Longitude and Latitude locate a ship on the earth. The right ascension is counted from the vernal equinox instead of the Greenwich meridian. The declination is just like latitude (Fig. 51).

SIDEREAL TIME

Sidereal Time is used when stars are observed. It is 0^h Sidereal Time when the point called the vernal equinox* is on the upper side of the meridian. The sidereal time at any instant is the hour angle (H. A.) of the vernal equinox (Fig. 52). A chronometer regulated to Sidereal Time will run faster than a chronometer keeping solar time, and will gain nearly 10^s every hour, or almost 4^m per day. Sidereal Time may be found from Civil Time by the following rule (Fig. 53, and Fig. 64, p. 183):

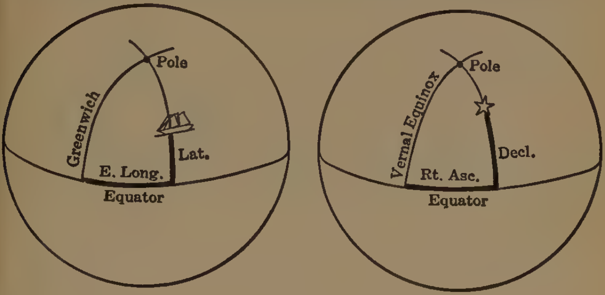


FIG. 51.

> **To change Greenwich Civil Time into Greenwich Sidereal Time add together the given Greenwich Civil Time, the "Sidereal Time of 0^h Civil Time at Greenwich" (or R. A. of Sun + 12^h) for the date,**

---

* The vernal equinox is the point on the celestial equator where the sun's center crosses it (about March 21) when going from the southern hemisphere into the northern hemisphere.

and the correction at the foot of the page for the Gr. Civ. T. (or Table III).

To change Local Civil Time into Local Sidereal Time first change the Local Civil Time into Greenwich Civil Time by adding the west longitude (or subtracting the east longitude). Then change to Greenwich Sidereal Time by the above rule. Finally change the Greenwich Sidereal Time to Local Sidereal Time by subtracting the west longitude (or adding the east longitude).

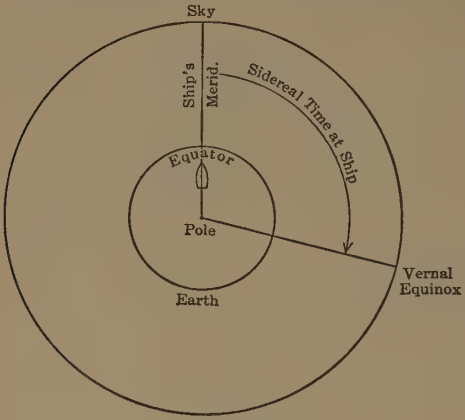


FIG. 52. Sidereal Time.

The correctness of this rule will be seen if you remember that we start out with the correct sidereal time for midnight (0^h) and, in order to find the sidereal time for any hour since midnight, say 4^h A.M., we must add on the 4^h because it is that much later. But the 4^h is in solar time. A sidereal chronometer would have run beyond 4^h in the same length of time, so we add the little correction

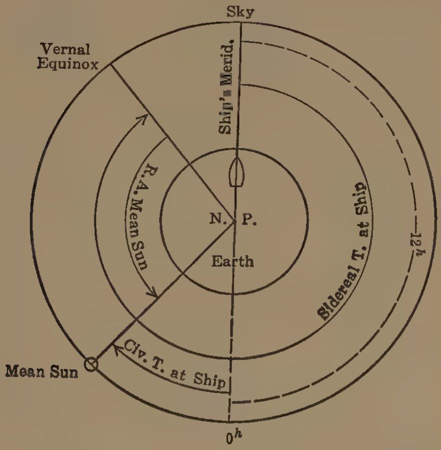


FIG. 53. Local Civil and Sidereal Time.

from Table III, or at foot of the page, to get just what a sidereal chronometer would have indicated.

The "Sidereal Time of 0^h Civil Time at Greenwich" will be found for each day of the year in the first table in the Almanac.

Example. The local civil time at ship is $4^h\ 31^m\ 10^s$ (A.M.) Jan. 1, 1925; Longitude, $3^h\ 20^m\ 00^s$ W. What is the Sidereal time at ship?

Local Civil time	4^h	31^m	10^s
Longitude W	3	20	00
Gr. Civ. Time	7	51	10
Sid. T. of 0^h Civ. T. at Gr.	6	40	30.4
Reduction for 7^h 51^m (foot p. 2)		1	17.4
Gr. Sidereal Time	14	32	57.8
Longitude W	3	20	00
Sidereal Time at Ship	11^h	12^m	$57^s.8$

THE NAUTICAL ALMANAC

The Nautical Almanac (N. A.) is issued for each year (in advance) by the U. S. Navy Dept. and contains data that are necessary for solving the problems of nautical astronomy. The student should examine the Almanac carefully and understand its arrangement and the various terms employed. Notice that nearly all the numbers are given for some instant of Greenwich Civil Time. It is therefore absolutely necessary to know the Greenwich time before the Almanac can be used. Beginning with the Almanac for 1925 Greenwich Civil Time is used, 0^h being the instant of midnight. Previous to that year Astronomical time was used, 0^h being the instant of noon. The result is that there will not now be any disagreement of dates as was formerly the case.

The following table is an extract from the page giving the sun's *declination* and the *equation of time* for the month of November, 1925. This part of the Almanac is the one most frequently used by the navigator.

SUN, NOVEMBER, 1925

G.C.T.	Sun's Declination	Equation of Time	Sun's Declination	Equation of Time
	Sunday 1.		Thursday 5.	
h	° ′	m s	° ′	m s
0	−14 11.8	+16 19.9	−15 27.5	+16 22.2
2	14 13.4	16 20.1	15 29.0	16 22.1
4	14 15.0	16 20.3	15 30.6	16 22.0
6	14 16.6	16 20.5	15 32.1	16 21.9
8	14 18.3	16 20.6	15 33.6	16 21.8
10	14 19.9	16 20.8	15 35.2	16 21.7
12	14 21.5	16 20.9	15 36.7	16 21.5
14	14 23.1	16 21.1	15 38.2	16 21.4
16	14 24.7	16 21.2	15 39.7	16 21.3
18	14 26.3	16 21.3	15 41.3	16 21.1
20	14 27.9	16 21.5	15 42.8	16 21.0
22	14 29.5	16 21.6	15 44.3	16 20.9
H.D.	0.8	0.1	0.8	0.1
	Monday 2.		Friday 6.	
0	−14 31.1	+16 21.7	−15 45.8	+16 20.7
2	14 32.7	16 21.8	15 47.3	16 20.5
4	14 34.3	16 21.9	15 48.8	16 20.4
6	14 35.9	16 22.0	15 50.3	16 20.2
8	14 37.5	16 22.1	15 51.9	16 20.0
10	14 39.0	16 22.2	15 53.4	16 19.8
12	14 40.6	16 22.3	15 54.9	16 19.6
14	14 42.2	16 22.4	15 56.4	16 19.4

SUN'S DECLINATION

The declination of the sun is the number of degrees the sun is north or south of the equator at any time (Fig. 54). If it is north it is marked +; if it is south it is marked −. It is given in the Almanac for every 2^h of the day beginning at midnight or 0^h.

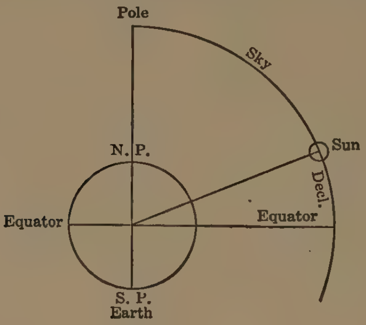


FIG. 54.

POLAR DISTANCE

If we subtract the declination from 90° we get the *polar distance*, which is sometimes wanted instead of the declination.

TAKING OUT THE DECLINATION

To take out the sun's declination for any hour and minute of Greenwich Civil Time.

Take out the declination for the nearest hour given in the table. Find the correction by multiplying the H. D. (hourly difference) by the fraction of an hour between the given time and the tabular time. Add or subtract the correction, whichever is necessary to bring the result between the preceding and following values in the table.

Example. Find the declination of the sun at $15^h\ 30^m$ Gr. Civ. Time November 1, 1925. From the table we find that for 14^h the declination is $-14°\ 23'.1$ and for 16^h it is $-14°\ 24'.7$. The value for 16^h is the nearest one in the table. The H. D. is $0'.8$. The difference between $15^h\ 30^m$ and 16^h is 30^m or $0^h.5$. $0^h.5 \times 0'.8 = 0'.4$. This must be subtracted from $14°\ 24'.7$ because the declination is smaller at 14^h, so it is smaller at $15^h\ 30^m$ than it is at 16^h. $14°\ 24'.7 - 0'.4 = 14°\ 24'.3$. The declination is therefore $-14°\ 24'.3$ or $14°\ 24'.3$ *South* of the equator.

When using the sun's declination for the purpose of finding latitude or longitude it is sometimes convenient to change the tenths of minutes to seconds. Each one-tenth of a minute equals 6 seconds (6″); that is, $0'.1 = 6''$; $0'.2 = 12''$, etc.

TAKING OUT THE EQUATION OF TIME

To take out the Equation of Time proceed just as for taking out declination.

Example. Suppose that we require the equation of time for Aug. 5, 1925 at $12^h\ 30^m$. From the Almanac we find for Aug. 5,

G.C.T.	Equation of Time
12^h 14^h	$-5^m\ 52^s.1$ $5\ \ 51\ .7$
	H.D. $0^s.2$

The equation of time for 12^h is the nearest one in the table. This is $-5^m\ 52^s.1$. To correct it multiply $0^s.2$ by $0^h.5$, the time since 12^h. This gives $0^s.1$ which subtracted from $-5^m\ 52^s.1$ gives $-5^m\ 52^s.0$, the equation of time at $12^h\ 30^m$. The minus sign before the equation of time means that it is to be subtracted from (mean) civil time to obtain apparent time. To get (mean) civil time from apparent time we must add this equation, that is, reverse the sign.

Example 1. The civil time is $12^h\ 30^m$ Aug. 5, 1925; what is the apparent time?

Civil time	$12^h\ 30^m$
Equa. Time	$-5^m\ 52^s.0$
Apparent Time	$12^h\ 24^m\ 08^s.0$

Example 2. The apparent time is $12^h\ 24^m\ 08^s.0$ Aug. 5, 1925; what is the mean civil time?

Apparent Time	$12^h\ 24^m\ 08^s.0$	
Equa. Time	$-5\ \ 52.0$	(change to +)
Civil Time	$12^h\ 30^m\ 00^s.0$	

The Nautical Almanac also gives data for the moon, planets and stars. The general arrangement of these tables is similar to that for the declination and equation of time. Their use will be explained later.

CORRECTING THE OBSERVED ALTITUDE

Before the observed altitude of the sun can be used for calculating latitude or longitude it must be corrected for the Index Error of the sextant (already mentioned), for the dip of the sea-horizon below the true horizon, for the effect of refraction and of parallax, and for the semi-diameter of the sun.

The sea-horizon is always below the true horizon by an amount which depends upon the height of the observer's eye above the water surface (Fig. 55). The true horizon is an imaginary circle in the sky at the height of the observer's eye, or just 90° from the point overhead. The higher you are above the water the higher the true horizon is above the apparent (sea) horizon.

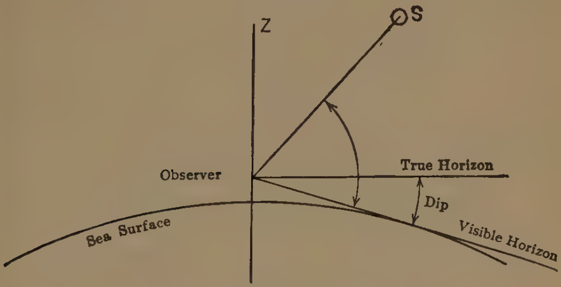
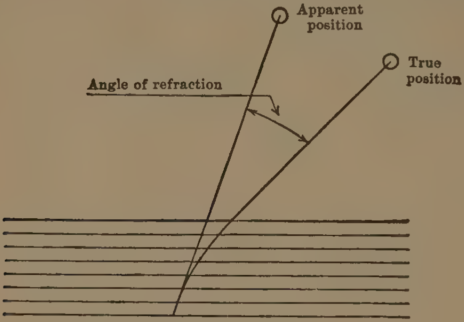


FIG. 55. Dip of the Horizon.

The number of minutes and seconds by which the sea-horizon dips below the true horizontal line may be taken from Table 14, Bowditch. This correction must be subtracted from the measured altitude. Since the height of eye must be known for each observation the navigator should determine beforehand the height of different parts of the vessel above the water surface by measuring with a tape.

The correction for refraction is made necessary by the fact that the rays of light from the observed object are bent into a curve when passing through the atmosphere, making the object appear to the observer to be higher above the horizon than it really is (Fig. 56). The amount of this correction for different altitudes may be taken from Table 20A, Bowditch. The correction for refraction is nothing for a point overhead, about 1′ for an altitude of 45°, and more than half a degree at the



ATMOSPHERIC REFRACTION

FIG. 56.

horizon. This correction is always subtracted from the measured altitude.

The parallax correction is a slight change in the apparent direction of the object due to the fact that the observer is on the surface instead of at the earth's center, to which point all observations are reduced (Fig. 57). The amount of this correction depends upon the distance of the object as well as upon the altitude. The parallax is never a large correction, except for the moon. For the sun it is always less than 9″. The amount of this correc-

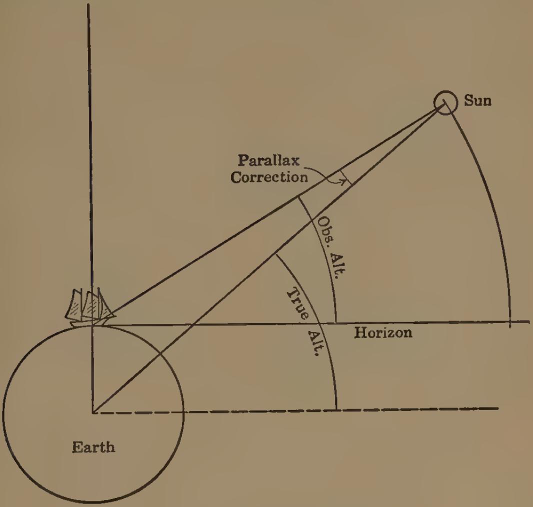


FIG. 57. Parallax Correction.

CORRECTING THE ALTITUDE

Dip, Table 14	−5′ 53″
Refraction, Table 20A	−1 53
I. C.	−0 20
	−8′ 06″

Semi. diam.	+15′ 54″
Parallax, Table 16	+8″
	+16′ 02″
	− 8′ 06″
Corr. =	+ 7′ 56″

Obs. alt. ⊙	27° 12′ 30″
Corr.	+ 7 56
h	27° 20′ 26″

tion for different altitudes will be found in Table 16, Bowditch. It is always added to the observed altitude.

Table 20B, Bowditch, gives the combined corrections for refraction and parallax of the sun. This, of course, would not be used for observations on any other object than the sun, because the parallax would not correspond.

The semi-diameter of the sun varies from about 15′ 45″ to 16′ 15″. Its value is given in the Nautical Almanac for every ten days. For many purposes it would be sufficient to take the correction as 16′. If we observe the lower limb (edge) of the sun we must add this correction to the measured altitude; if the upper limb is observed the correction must be subtracted.

Example. May 1, observed alt. $\underline{\odot}$ (sun's lower limb) = 27° 12′ 30″; I. C., – 20″; Ht. of eye, 36 ft.; find the true altitude of the center, h. The work of correcting this altitude is shown on p. 148.

The separate corrections may always be looked up in this manner (p. 148) if desired, or if required by an examiner, but it need never be done in practice. As a general rule Table 46 would be used as explained in the next paragraph.

ALL CORRECTIONS COMBINED

Table 46, Bowditch, contains corrections to the sun's altitude for different heights of the observer's eye and for different measured altitudes. This combined correction includes the corrections for dip, refraction, parallax and semi-diameter, the latter being taken as 16′. In order to make allowance for the small variation in the semi-diameter at different dates a small table is added at the bottom of the page, from which a second correction may be taken out according to the time of the year. This table (46) can be used only when the observation is taken on the **lower** limb of the sun.

In another column to the right of the sun's correction is the star's correction of altitude. This is the same as the first, but with the semi-diameter and parallax corrections omitted. These two corrections are too small to measure in case of an object as far away as a star. Neither of these columns should be used for observations on the moon. It will be noticed that this table includes all corrections except the I. C. This, of course, could not be included conveniently in a general table. Combine the I. C. with the correction in Table 46 to get the "Correction to altitude." For all ordinary observations it is unnecessary to look up the separate corrections as was done on p. 148. Careful attention should be given to the + and − signs of the corrections.

Example. May 1, observed alt. $\underline{\odot}$ (sun's lower limb) = 27° 12′ 30″; I. C., −20″; Ht. of eye, 36 ft. Find true altitude of center, *h*.

Obs. alt. $\underline{\odot}$	27° 12′ 30″	Tab. 46	+8′ 22″
Corr.	+7′ 54″	Aux. Tab.	−8″
h.	27° 20′ 24″	I. C.	−20″
		Corr. to alt.	+7′ 54″

The refraction correction is large near the horizon and if the actual temperature and air pressure are very different from those for which the table is computed there may be considerable error due to this cause. For this reason it is best not to measure an altitude when the object is within 10° of the horizon.

PROBLEMS

1. The alt. $\underline{\odot}$ June 21, was 48° 40′; I. C., −10″; ht. of eye, 50 ft. What is the true altitude?

Ans. 48° 47′ 55″.

2. Obs'd alt. $\underline{\odot}$ July 1, 41° 10′ 10″; ht. of eye, 26 ft.; I. C., + 1′ 10″. What is the corrected altitude?

Ans. 41° 21′ 06″.

3. Obs'd alt. $\underline{\odot}$ July 30, 61° 41′ 20″; ht. of eye, 48 ft.; I. C., −2′ 00″. What is the corrected altitude?

Ans. 61° 47′ 51″.

4. Obs'd alt. of *Polaris*, 43° 10′; ht. of eye, 18 ft.; I. C., 0″. What is the true altitude?

Ans. 43° 04′ 50″.

CHAPTER VIII

LATITUDE

THE latitude of a vessel is her distance in degrees north or south of the equator, measured along a meridian. It is also the angular distance from the celestial equator to the point in the sky directly overhead (Zenith), for these two are equal to each other as will be seen from Fig. 58; that is, the number of degrees in *QO* equals the

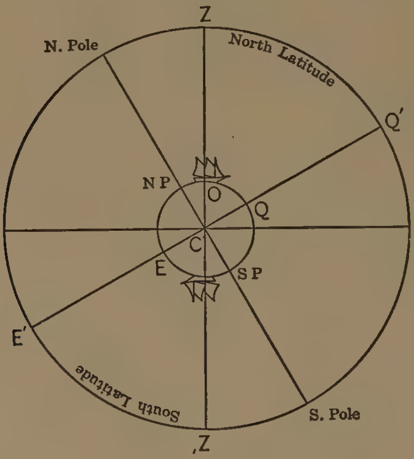


FIG. 58. Latitude.

number of degrees in $Q'Z$. It is also the angle between CO and CQ. Since latitude and declination are measured in exactly the same way, the latitude is the declination of the Zenith (Z).

LATITUDE BY MERIDIAN ALTITUDE OF THE SUN

The meridian altitude is the altitude taken when the sun bears true south or true north. It is the highest altitude the sun reaches during the day (unless the vessel is moving very rapidly north or south). At this time it is 12 o'clock (noon) local apparent time. This gives us two ways of knowing when to observe the altitude. We may take the altitude when the chronometer shows that it is noon of local apparent time, or we may begin taking the altitude a little before noon, continuing the observation until the highest altitude is reached. Some prefer to use the time for indicating when to make this observation. In this case it is best to set a watch to the exact apparent time at the place where the ship will be at noon and take the altitude when the watch says 12^h. This saves a little time because only one altitude needs to be taken. Probably the majority prefer the old way of beginning 15 to 30 minutes before apparent noon, measuring the altitude of the sun (lower limb) and noting the number of minutes increase in the altitude. As soon as the altitude is seen to grow smaller the noon altitude is passed, and the highest altitude noted is taken as the meridian altitude. This takes a little longer but is perfectly safe, as errors in the watch have no effect. Note whether the sun bears north or south. This is important when the latitude is nearly equal to the sun's declination, as for example, when you are passing the sun, going into the tropics.

This highest altitude must now be corrected to obtain the true central altitude, often written T. C. A., or *h* in the calculations. If the true meridian altitude is subtracted from 90° the remainder is the true meridian zenith distance (*Z* to Sun, Fig. 59), because it is 90° from the true horizon *S* to *Z*. If the corrected declination (Equator to Sun) is added to (or subtracted from) the meridian zenith distance the result is the latitude of the observer.

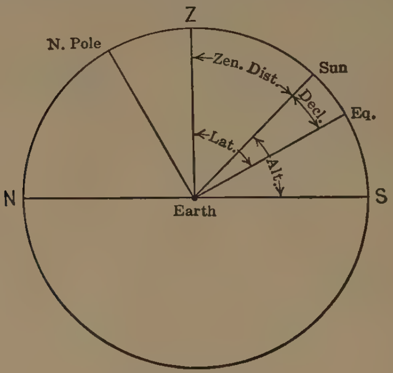


FIG. 59. Latitude.

If the sun bears south mark the zenith distance (Z. D.) North. If the sun bears north mark the Z. D. South. If the declination is + mark it North;

> **if it is – mark it South. Then add the Z. D. and Decl. if they are of the same name (both N or both S); take the difference if they are of different names, and mark the result with the name of the greater.**

The declination is always North in the summer in the northern hemisphere (March 21 to Sept. 22); in winter (Sept. 22 to March 21), it is South.

Example. Observed meridian altitude of $\underline{\odot}$ July 6, 1925 = 67° 48′ 00″, bearing South. Height of eye, 36 feet; index correction, +2′ 00″; Longitude 67° 27′ W. Required the latitude.

LATITUDE BY MERIDIAN ALTITUDE

Obs. alt. ⊙	67° 48′ 00″
Corr.	+11 34
h	67° 59′ 34″
90°	89 59 60
Z. D.	22° 00′ 26″ N
Decl.	22 42 19 N
Lat.	44° 42′ 45″ N

Table 46	+9′ 34″
I. C.	+2 00
Corr.	+11′ 34″

Decl. at 16^h G. C. T. =	+22° 42′.5
Corr.	.18
Decl. =	+22° 42′.32
=	+22° 42′ 19″

H. D. = 0′. 3
G. T. = 0^h. 6
Corr. = 0′.18

Long. =	4^h 29^m 48^s
Loc. App. Time	12 00 00
Eq. t.	−4 30
G. C. T. =	16^h 34^m 18^s
=	16^h.6

LATITUDE BY USE OF A "LATITUDE CONSTANT"

Some prefer to work the latitude a different way. We can tell pretty nearly what the noon altitude will be even before we measure it because we have a D. R. Lat., or we may take an altitude a little before noon and allow for the run. The object of this is to get the altitude near enough to take out its correction beforehand. Then if the real noon altitude is a little different that will not affect the correction. The index correction should also be found beforehand. Then we may take out the correction to the altitude and complete all of the calculation before noon except subtracting the altitude when we get it. The number we calculate before noon is called the "Latitude Constant." This "constant" is 90° minus the correction plus the declination (when the Lat. and Decl. are of the same name, and Lat. greater than Decl.). Working the same altitude as given on p. 155 we get:

	90°	
Corr.	(−) 11′ 34″	
	89° 48′ 26″	
Decl.	+22 42 19	N
Constant	112° 30′ 45″	

When the altitude 67° 48′ 00″ is found at noon subtract it.

Constant	112° 30′ 45″	
Obs. Alt.	67 48 00	
Lat.	44° 42′ 45″	N

This gives the latitude very quickly. The whole latitude calculation is so simple, however, that there is only a little gained by the use of this constant, especially if you have your Decl. and Corr. all ready before noon. In that case the first method is about as quick. The constant is different for different altitudes and declinations, so it must be figured each time separately.

If the Decl. and Lat. are of opposite names the Decl. must be subtracted. If the Lat. and Decl. are of the same name, but the Decl. is the greater, subtract the Decl.

EXAMPLES

1. Lat., 30° S; Decl., 10° N; Corr., +9′. Lat. Const. is 79° 51′.

2. Lat., 10° N; Decl., 20° N; Corr., +10′. Lat. Const. is 69° 50′.

THE OLD 89° 48′ RULE

The method just described leads us to consider an old rule formerly much used. The navigators who used this rule assumed that the correction to the altitude was always the same and equal to 12′. This gave 89° 48′ for a constant. To this they added the declination and then subtracted the altitude (corrected for I. C.). Applied to the preceding latitude observation this rule would give:

Const.	89° 48′ 00″	
Decl.	22 42 19	N
	112° 30′ 19″	
Obs. Alt. (+I. C.)	67 50 00	
Lat.	44° 40′ 19″	N

This is only a little over 2′ in error and does not look so bad. Under some conditions, however, the error may be much more, as for example when the altitude is small and the height of eye is large. Suppose that the obs. alt. is 10° 00′, I. C. = 0′, ht. of eye 36 ft., Decl. = 23° S. Working it first by the correct rule:

Obs. Alt.	10° 00′
Corr.	+5 15
h	10° 05′ 15″
90°	
Z. D.	79° 54′ 45″ N
Decl.	23 00 00 S
Lat.	56° 54′ 45″ N

BY THE 89° 48′ RULE

	89° 48′
Decl.	23 00 S
	66° 48′
Obs. alt.	10° 00′
Lat.	56° 48′ N

This is nearly 7 miles in error; and it is in a high latitude and in midwinter when 7 miles may be a serious matter. The trouble with the rule is that it makes no allowance for changes in dip at different heights and changes in refraction at different altitudes; consequently it should not be used. Results worked by this rule on examinations will not be accepted by the Local Inspectors.

LATITUDE BY EX-MERIDIAN ALTITUDE

Sometimes it is impossible to get the altitude exactly at the instant of noon, on account of clouds; or the navigator may wish to know the latitude a little before the instant of noon. In this case take the altitude a little before or a little after noon, note the exact time of the sight, and then use the following rule.

> **Change the Gr. Civ. Time into Loc. App. Time by adding the Equation of Time and subtracting the west longitude. Then from Table 26 Bowditch, with Lat. and Decl., take out the "variation of altitude"; with this number and the number of minutes from noon enter Table 27 and take out the "reduction." Add this reduction to the observed altitude. Complete the calculation of latitude by the first rule.**

The "variation of altitude" is the amount the sun is below the meridian altitude one minute (either way) from noon. The reduction is the amount the obs. alt. is below the meridian alt. If the interval before or after noon is greater than 26^m the method should not be used. Notice that it is necessary to know the local time accurately and that this depends upon the D. R. Long. The position you get is not the noon latitude but is the Lat. at the time of the observation. To get the noon Lat. allow for the run to noon.

In using Table 26 the Latitude is needed, and that is what you are trying to find. However, you do not need a very accurate Lat. to use Table 26; the D. R. Lat.

LATITUDE BY EX-MERIDIAN

Alt. ⊙	66° 21′ 00″		Table 46		+9′ 31″	Chron.	$16^h\ 51^m\ 58^s$
Corr.	+9 41		I. C.		+10	C. C.	−1 30
h	66° 30′ 41″		Corr.		+9′ 41″	G. C. T.	$16^h\ 50^m\ 28^s$
at^2	+19 51					Eq. T.	−5 44
H	66° 50′ 32″		Table 26, $a = 3''.3$			Gr. App. T.	$16^h\ 44^m\ 44^s$
Z. D.	23° 09′ 28″	N	Table 27	3″,	18′ 03″	Long. W.	4 25 48
Decl.	21 30 41	N		0.3″,	1 48	Loc. App. T.	$12^h\ 18^m\ 56^s$
Lat.	44° 40′ 09″	N	at^2		19′ 51″	Time from Noon	$18^m\ 56^s$

Decl. 16^h	+21°	31′.0
Corr.		.32
Decl.	+21° 30′.68	
	+21° 30′ 41″	
	H. D.	0′.4
	G. T.	$0^h.8$
	Corr.	0′.32

may be used, or you may work up the observation just as though it were a noon sight and get a Lat. that is close enough for this purpose.

Example. July 15, 1925, obs. alt. = 66° 21′ 00″, bearing south; chron. $16^h\ 51^m\ 58^s$; chronometer correction, $1^m\ 30^s$ fast; I. C., +10″; height of eye, 36 ft.; Lat. by D. R. 44° 50′ N; Long. by D. R., 66° 27′ W.

EXPLANATION OF EXAMPLE

The Gr. App. Time is found by adding the Equa. of Time to the G. C. T. The Loc. App. Time is found by subtracting the West Long. (in hours) from the Gr. App. Time. (If Long. is East, add to Gr. App. T.). The "time from noon" is the difference between Loc. App. Time and 12^h. Notice that the correction (at^2) is taken out by parts, that is the 3″ and the 0″.3 are looked up separately and the results added. (See p. 161.)

LATITUDE BY MERIDIAN ALTITUDE OF A STAR

Observations on stars are more difficult than observations on the sun, chiefly because the horizon becomes difficult to see by the time it is dark enough to see the stars easily. The planets and the brightest stars do not give much trouble, but the pole star (*Polaris*) and the fainter stars are sometimes hard to get. For a short time during twilight or on moonlight nights the horizon can be seen well enough to get star sights. It will help greatly to have sextant mirrors that are bright and clean. For star work they need to be re-silvered oftener than for sights on the sun.

The observation for latitude by meridian altitude of a star is made by taking the highest altitude just as when taking the sun at noon, but it is convenient to know beforehand the time when the star will cross the meridian.

When taking the altitude the star may be more easily found by setting the index of the sextant to read the approximate meridian altitude by the star. This will bring the star's image somewhere in the field of view so that it may be more quickly found. The approximate altitude may be found by subtracting the Lat. from 90° and adding the Decl. if of the same name as the Lat., subtracting if of opposite name.

Example. In Lat. (by D. R.) 44° 50′ N, Decl. of *α Scorpii*, −26° 15′ (S), find approximate altitude of star.

Lat. 44° 50

90° −Lat. 45° 10′
Decl. −26 15
Approx. Alt. 18° 55′

If the star cannot be found in the mirror when sighting the south horizon it may be found by "pulling down" the star, as it is called. Set the sextant to read 0°, and sight at the star direct. There will be no difficulty in seeing it this way. Lower the sextant slowly and at the same time move the index arm out. In this way you can keep the star in view in the sextant all the time until you see the horizon. The star may then be set on the horizon and the index arm clamped.

The calculation of latitude by this observation is the same as for the sun except that the correction for altitude is taken from Table 46 from the column marked "star's correction" and is always subtracted. The declination of the star may be taken from the N. A. in the table of "Apparent Places of Stars." It need not be corrected for the hours of the Greenwich Time.

Example. Obs. alt. of *α Scorpii*, Aug. 1, 1925, 19° 05′ 00″, bearing South; ht. of eye, 18 ft.; I. C., +30″. From the N. A. the star is found to pass the meridian at $19^h 45^m$ ($= 7^h 45^m$ P.M.); the Decl. is −26° 16′.0. Find the latitude.

Obs. alt.	19° 05′ 00″			
Corr.	−6 27		Tab. 46	−6′ 57″
h	18° 58′ 33″		I. C.	+30
Z. D.	71 01 27	N	Corr. to Alt.	−6′ 27″
Decl.	−26 16 00	S		
Lat.	44° 45′ 27″	N		

Stars suitable for meridian observations may be selected by consulting the table in the N. A. headed "Meridian Transit of Stars 19—." For instance, if it is 7^h P.M. ($= 19^h$) local time, Aug. 1, 1925, the D. R. Lat. is 44° 55′ N, and you wish to get latitude, look in the table and you find that *δ Scorpii* transits at $19^h 16^m$, *α Scorpii* at $19^h 45^m$ and *Tri. Aust.* at $20^h 01^m$. Referring to the table of "Apparent Places of Stars," or to the star chart at the back of the N. A., you will find that *α Tri. Aust.* is too far south to be visible, its declination being −68°. Either *δ* or *α Scorpii* may be used, but *α* is brighter, that is, its magnitude is a smaller number, 1.2, so use *α Scorpii.*

To find the exact time of meridian passage (transit) of a star:

Take from the table " Meridian Transit of Stars 19— " the time of transit of the star for the first day of the month. Then subtract from this time the correction given on the next page for the day of the month. The result is the local time of transit for the desired date.

The time of meridian passage may also be found by subtracting the "Sidereal time of 0^h Civ. T. at Gr." from the Right Ascension of the star as given in the table "Apparent Places of Stars, 19—."

LATITUDE BY MERIDIAN ALTITUDE OF THE MOON

The time at which the moon will pass the meridian may be taken from the N. A. for the instant of transit over the Greenwich meridian, and then corrected for the longitude by means of Table 11, Bowditch.

Example. Suppose we wish to find the time of transit of the moon over the meridian 67° 22′ W (= 4^h 29^m 28^s W) on July 29, 1925. The time of transit for July 29, 1925 is given as 18^h 39^m, Gr. Civ. Time, and the difference for one day is 53^m. In Table 11, Bowditch, we find for Long. 65° and "daily variation" 53^m, a correction of 10^m, which is to be added.

Gr. Civ. Time of Gr. Transit	18^h 39^m
Corr.	+10
Loc. Civ. Time of Loc. Transit	18^h 49^m
Long. W.	4 29
Gr. Civ. Time of Local Transit	23^h 18^m

The observation should be begun a little before the chronometer indicates the computed time $23^h\ 18^m$. It will be necessary to observe the upper or the lower limb according to which is visible. Only one can be observed except near the time of full moon. The observed altitude requires a different correction from the sun or stars, because the moon's parallax is very large, about a degree in some cases. The observed altitude may be corrected by means of Table 49, Bowditch. This table gives the correction for a height of eye of 35 feet. For other heights a further correction is necessary; it may be taken from a little table which follows Table 49. The moon's declination and its horizontal parallax (H. P.) may be taken from the N. A. in the table headed "Moon, 19—." The declination of the moon changes more rapidly than that of the sun so it must be corrected carefully. After the declination and altitude have been corrected the rest of the calculation for latitude is the same as for the sun or a star.

Example. Meridian alt. moon's upper limb, July 29, 1925, was 35° 07′ 00″, bearing south. Loc. Civ. T. $18^h\ 49^m$. Long., 67° 22′ W, Ht. of eye, 12 ft., I. C., +10.″

Obs. Alt.	35° 07′ 00″
Corr. to Alt.	+27 14
h	35° 34′ 14″
Z. D.	54° 25′ 46″ N
Decl.	12 55 30 S
Lat.	41° 30′ 16″ N
Loc. Time	$18^h\ 49^m$
Long.	4 29
Gr. Time	$23^h\ 18^m$

	Table 49
H. P. 58′.2	+24′ 40″
Corr. 12 ft.	+2 24
I. C.	+10
Corr. to alt.	+27′ 14″
Decl. at 24^h	−13° 02′.3
Corr.	6′.8
Decl.	−12° 55′.5
Diff. for 2^h	19′.5

42
390
780
120)819.0(6′.8
720
990
960

or by Table IV, N. A., corr. = 6′.8

NOTE. — The declination is corrected by taking from the Decl. at 24^h (0^h of July 30), forty-two one-hundred-twentieths of 19′.5, the difference for 2 hours. The 42^m is the time before 24^h and the 120^m is the two hour interval. This proportional part may be looked up directly in Table IV, N. A., by finding the 195 at the top and 42^m at the left.

LATITUDE BY MERIDIAN ALTITUDE OF A PLANET

The latitude is found from the meridian altitude of a planet in just the same way as for a star, except that the declination must be corrected for the Greenwich Time. The declination of a planet changes slowly and so is given for Greenwich 0^h (midnight) each day instead of every 2 hours. The correction for the declination may be made by Table IV, N. A., by finding the difference at the top and the Greenwich Time at the right.

LATITUDE BY ALTITUDE OF THE POLE STAR

(*Polaris*)

The altitude of the pole star may be taken at any time that it is visible and the chronometer time noted. The latitude is then found by the rule:

> **Change the Gr. Civ. Time into Greenwich Sidereal Time by adding to it the "Sidereal Time of 0^h Gr. C. T.," and the correction at the foot of the same page (N. A.) for the hours and minutes of the Gr. Civ. T. Subtract the W. Long. (or add E. Long.); the result is Loc. Sid. Time. Look in Table I, N. A., for the correction to the altitude of Polaris. The obs. altitude is to be corrected as usual for dip and refraction (Table 46) and then for this corr. from Table 1. The result is the N. Lat.**

Example. Obs. Alt. of *Polaris*, Aug. 1, 1925, at Chronometer time $1^h\ 01^m\ 30^s$, was 44° 14′ 00″; C. C., $-0^m\ 30^s$; ht. of eye 30 ft.; Long. 67° 22′ W.

Chron.	$1^h\ 01^m\ 30^s$
C. C.	−30
G. C. T.	$1^h\ 01^m\ 00^s$
Sid. T. 0^h	20 36 20
Corr.	10
Gr. Sid. T.	$21^h\ 37^m\ 30^s$
Long. W.	4 29 28
Loc. Sid. T.	$17^h\ 08^m\ 02^s$

Obs. Alt.	44° 14′ 00″
Tab. 46 (Bowditch)	−6 23
	44° 07′ 37″
Corr. Tab. I, N. A.	+39 36
Lat.	44° 47′ 13″ N

The pole star (*Polaris*) can be seen only in the northern hemisphere so the Lat. must be N.

It will assist in finding Polaris if its altitude is computed beforehand. To do this take the best known latitude of the ship at the time of the observation and simply work the problem backward to obtain the altitude. If this altitude is set off on the sextant the star should appear in the mirror.

PROBLEMS

1. On July 5, 1925, the merid. alt. ⊙ was 70° 10′, bearing south; I. C., −2′ 00″; ht. of eye, 36 ft.; Corrected Declination, +22° 48′ 24″. Find the latitude.
Ans. 42° 30′ 49″ N.

2. A vessel in Lat. 39° 00′ N, Long. 56° 10′ W (by D. R.), sails S 63° W, by compass, 90 miles to noon position. The varia. is 19° W; the devia. is 6° E. At noon, Aug. 10, 1925, the obs. merid. alt. ⊙ was 67° 32′ bearing south; the ht. of eye, 36 ft.; I. C., +1′ 00″; chron. time $15^h\ 56^m$. Decl. at 16^h, +15° 36′.2 H. D., 0′.7;

Equa. of Time, $-5^m\ 14^s.0$; H. D., $0^s.4$. What is the error in the D. R. Lat.? *Ans.* 8.5 mi. too far N.

3. Obs. merid. alt. $\underline{\odot}$ 18° 10′; bearing N; ht. of eye, 26 ft.; I. C., + 1′ 00″; Gr. Civ. T., $14^h 30^m$, June 25, 1925. Decl. at 14^h, + 23° 24′.1; H. D., 0′.1 (decreasing). Find the Lat. *Ans.* 48° 16′.9 S.

4. On July 26, 1925, obs. alt. $\underline{\odot}$ 64° 18′ bearing S and W; I. C., + 15″; ht. of eye, 8 ft.; Chronometer, $16^h\ 51^m\ 32^s$; C. C. $-1^m\ 27^s$; Long., $4^h\ 25^m\ 26^s$; Decl., + 19° 27′.7; Equa. of Time, $-6^m\ 20^s.5$. Find the Lat. (by Ex.-meridian). *Ans.* 44° 40′ 06″ N.

5. On Jan. 28, 1910, in Lat. 42° 40′ N, Long. 70° 04′ W, the obs. alt. $\underline{\odot}$ is 28° 30′ 00″, bearing S and E; Gr. Time $4^h\ 27^m\ 38^s$ P.M.; ht. of eye, 30 ft.; I. C., + 10″ (off the arc); Equa. of time, $-13^m\ 03^s$; corrected Decl., −18° 18′ 20″. Find the Lat. *Ans.* Lat. 42° 44′ 26″ N.

6. Observed merid. alt. *Antares*, 21° 30′ 30″ (south); ht. of eye, 26 ft.; I. C., + 30″; Decl., − 26° 15′.1. Find the Lat. *Ans.* 42° 21′ 21″ N.

7. Obs. Alt. *Polaris*, Sept. 22, 1925, 40° 17′. The Gr. Civ. Time is $1^h\ 19^m\ 00^s$, Long. 61° 00′ W; ht. of eye, 30 ft.; I. C., 0″. Find the Lat. The Sidereal time of 0^h Gr. Civ. T. is $0^h\ 01^m\ 21^s$; the correction for G. T. is $0^m\ 13^s$; Corr. from Tab. I (N. A.) is − 0° 27′.6. Find the N Lat. *Ans.* 39° 42′ 54″ N.

8. Obs. alt. $\underline{\odot}$ 69° 21′ 30″, bearing N; I. C., − 1′ 10″; ht. of eye, 18 ft.; Decl., + 9° 00′ 26″. Find the Lat. *Ans.* 11° 27′ 42″ S.

9. Obs. alt. $\underline{\odot}$ Jan. 20, 1910, 20° 05′; I. C., 0″; Gr. App. Time, $13^h\ 35^m\ 28^s$; Lat. by D. R., 49° 20′ N; Long. by D. R. $1^h\ 10^m\ 20^s$ W; ht. of eye, 16 ft.; Decl. at 12^h Gr. Civ. Time, −20° 15′.0; H. D., 0′.5. Equa. of Time, $-11^m\ 02^s$. Find the Lat.

Ans. 49° 17′ 25″ N.

CHAPTER IX

LONGITUDE

THE longitude of a place east or west of Greenwich is the number of degrees, minutes and seconds measured along the equator between the Greenwich meridian and the meridian through the place. It is also the angle at the pole between these two meridians, because this angle is always the same as the arc of the equator. Since there is a fixed relation between the number of hours and the

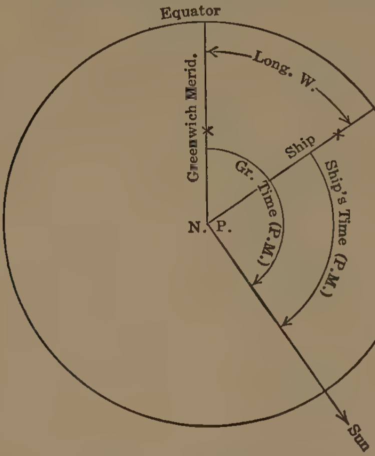


FIG. 60. Longitude and Time.

number of degrees in a circle, longitude may be expressed in either one of these units. The determination of longitude depends upon determining the (local) time at the ship and the time at Greenwich at the same instant.

In Fig. 60 the Gr. App. Time (P.M.) is 9^h and the App. Time (P.M.) at ship is 6^h. The difference (3^h) is the west longitude of the ship expressed in hours; that is, the Longitude is 45° W. If the time is counted from midnight, as shown in Figs. 61 and 62, the difference between the Greenwich Apparent Time 21^h and the Apparent Time at ship, 18^h, is the arc of the equator G′S′ which is 45° or 3^h. This is always equal to the arc of the equator GS. The difference of the times is therefore equal to the longitude. If a star is used the longitude

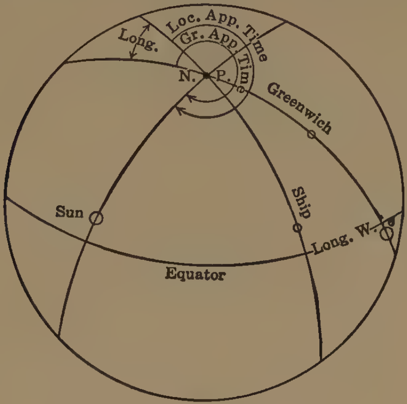


Fig. 61. Longitude and Time.

is the difference between the Greenwich Hour Angle and the Local Hour Angle (at ship) as shown in Fig. 63.

The method commonly used for determining longitude is that known as the "time sight" or "chronometer sight." This consists in measuring the altitude of the sun when it is nearly east or west of the observer, and then calculating the Apparent Time at ship. The chronometer always gives Greenwich Civil (mean) Time and from this the Greenwich Apparent Time may be found. The difference between the Greenwich Apparent Time and Apparent Time at ship is the longitude from Greenwich. If the Greenwich Time is greater (later) than Local Time the longitude is west; if less it is east.

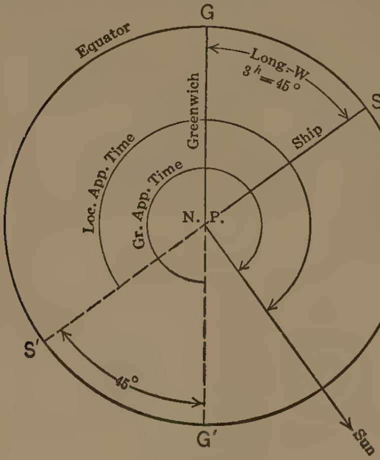


FIG. 62.

The hour angle of the sun may be found by solving the spherical triangle formed by arcs of great circles on the sphere through the pole, zenith and sun. From this hour angle the Apparent Time at ship may be found. In order to solve this triangle you need to know (1) the corrected altitude, *h*, (2) the sun's polar distance, and (3) the latitude of the ship. The polar distance is the angular distance from the north pole when you are in the northern hemisphere. It is found by adding the declination to 90° if the Decl. is south; subtracting the Decl. from 90° if Decl. is north. The Lat. should be the best Lat. known at the time and is usually the D. R. Lat.

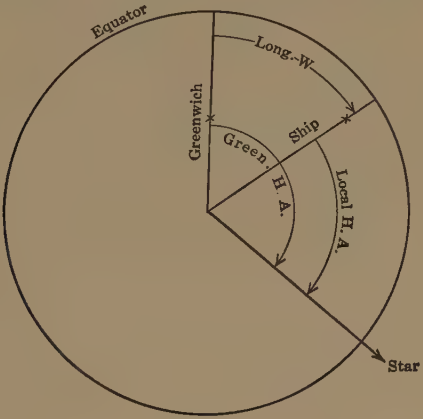


FIG. 63.

TAKING THE ALTITUDE

It is possible to work the "time sight" when the sun is not near east or west, but the results will not be so good if the sun is anywhere near the meridian (south). To find the best time to observe look in the Azimuth Tables (H. O. No. 71) under the Lat. and the date and find what apparent time corresponds most nearly to an azimuth of 90°. This apparent time corrected for Equation of time and for longitude will give the Greenwich time when the sun is East or West. (See p. 191 for use of Azimuth Tables.)

Example. On July 8, 1925, P.M., Lat. 45° N, Decl. $+22\frac{1}{2}°$, when is the sun due West? From the Azimuth Tables an azimuth of 90° corresponds to $4^h\ 20^m$ P.M., or $16^h\ 20^m$ App. Time. Adding the Equa. of Time, 5^m, and the longitude, $4^h\ 26^m$, we find the Greenwich Civil Time to be $20^h\ 51^m$.

In measuring the altitude it is good practice to take several sights in succession instead of only one. Each time that the altitude is measured the watch or chronometer should be read. By noticing the differences in the altitudes and in the times you can detect any large mistake in either one. They should run very regularly. A convenient way to take these altitudes is to sight the sun so as to find the approximate altitude, and then to set the index on some line on the arc a little farther ahead, say on the 29° 10′. Watch the sun's image until the lower edge (limb) is in contact with the horizon. At this instant note the watch time. Some prefer to use a stop watch for this purpose, starting it on a whole minute of the chronometer and stopping it at the instant the sun's limb is on the horizon. Next set the index at 29° 20′ and repeat the observation. Finally set on 29° 30′ and make a third observation. If any of these look wrong take some more readings. In taking the observations the observer will usually need an assistant to read the watch and record the altitudes and times. In this case he calls "stand by" when the sun's limb is nearly on the horizon and "Time" or "Mark" when the sun is exactly on. The index correction should be found immediately after or before the sight. The watch should be carefully compared with the chronometer.

In working up the sight, some prefer to select two of the altitudes and work them out separately to see if they agree. If they do not agree then a third altitude may be worked out to see which is right. This will help detect errors in the work. Others prefer to take the average of the three altitudes and the average of the three times and work these up as though they were one sight. This increases the accuracy of the result, because the mean of three is better than one.

FINDING THE GREENWICH APPARENT TIME

From the watch times and the comparison with the chronometer, get the chronometer time of the sight. Add or subtract the C. C. to get Greenwich (mean) Civil Time. Add the Equation of Time to get Greenwich Apparent Time.

SOLVING THE TRIANGLE

Add together the corrected alt. (h), the Lat. by D. R. (L) and the polar distance (p). Divide the sum by 2 and from this "half sum" (s) subtract the altitude (h) to get the "remainder" ($s - h$). Then take from Table 44 the following four logarithms and add them together; secant of Lat., cosec of polar dist.; cosine of "half sum," and sine of "remainder." This sum is the log haversine of the hour angle. Find this log hav. in Table 45 (haversines) and take from the top of the page the time corresponding, which will be the hour angle. This hour angle is to be subtracted from 12^h if it is A.M. at ship; added if it is P.M. at ship. The result is the Local Apparent Time.

If p is greater than 90° find the minutes at the left hand side of the page above the degrees (or, what is the same thing, take out the secant of the Decl.). The characteristic, or index, of the log will usually be 10 for the sec. or cosec, and may be omitted. The characteristic for the sin and cos will usually be 9 and must be kept. The characteristic for the sum of the 4 logs (haversine) will usually be 18 or 19 and must be called 8 or 9 when looking in Table 45. The log hav. is given for every second of time so it is usually sufficient to take the nearest number in the table and is seldom necessary to interpolate to get the time closer. If the time is to be changed into degrees Table 45 is very convenient for this purpose because the time and its equivalent in degrees are side by side at the top of the table. Table 50 may also be used for this purpose.

TO FIND THE LONGITUDE

Take the difference between the Greenwich Apparent Time and the Local Apparent Time, which gives the longitude in hours, minutes and seconds. Convert this into degrees, minutes and seconds. If the Greenwich Time is later than the ship's time the longitude is west; if earlier it is east.*

Example 1. July 8, 1925, P.M., three alts. of $\underline{\odot}$ are taken as follows:

alt. $33^\circ\ 25'\ 00''$, watch, $4^h\ 11^m\ 33^s$;
alt. $33^\circ\ 36'\ 00''$, watch, $4^h\ 12^m\ 33^s$;
alt. $33^\circ\ 46'\ 00''$, watch, $4^h\ 13^m\ 28^s$.

The I. C. is $0''$. Height of eye, 36 ft. Chronometer correction, $-\ 08^s$. Before taking the sights the watch and chronometer were compared. The chronometer read $20^h\ 40^m\ 00^s$, the watch $4^h\ 05^m\ 08^s$. The chronometer therefore reads $16^h\ 34^m\ 52^s$ greater than the watch and this amount should be added to the watch readings to get chronometer time. The Lat. by D. R. is $44^\circ\ 43'\ 15''$ N. The mean of the three altitudes is $33^\circ\ 35'\ 40''$ and the mean of the three watch readings is $4^h\ 12^m\ 31^s.3$. The rest of the computation is shown on p. 180.

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* "Greenwich time least, longitude east; Greenwich time best, longitude west."

Watch	$4^h\ 12^m\ 31^s.3$
Chr. – Wch.	$16\ \ 34\ \ 52$
Chron. T.	$20^h\ 47^m\ 23^s.3$
C. C.	$-08\ .0$
Gr. Civ. T.	$20^h\ 47^m\ 15^s.3$
Equa. T.	$-4\ \ 50\ .6$
Gr. App. T.	$20^h\ 42^m\ 24^s.7$

Mean alt.	$33°\ 35'\ 40''$
Corr.	$+8\ \ 33$
$h =$	$33°\ 44'\ 13''$
Table 46	$+8'\ 47''$
	-14
I. C.	0
Corr.	$+8'\ 33''$

Decl. 20^h	$+22°\ 28'.6$
Corr.	$.24$
Decl.	$+22°\ 28'.36$
=	$+22°\ 28'\ 22''$
$p =$	$67°\ 31'\ 38''$

H. D.	$0'.3$
G. T.	$0^h.8$
Corr.	$0'.24$

Equa. T. 20^h	$-4^m\ 50^s.3$
Corr.	$.32$
Equa. T.	$-4^m\ 50^s.62$

H. D.	$0^s.4$
G. T.	$0^h.8$
Corr.	$0^s.32$

h	$33°\ 44'\ 13''$
L	$44\ \ 43\ \ 15$
p	$67\ \ 31\ \ 38$
	$2)145\ \ 59\ \ 06$
s	$72°\ 59'\ 33''$
rem.	$39°\ 15'\ 20''$

sec.	0.14841
csc.	0.03430
cos.	9.46613
sin.	9.80125
log hav.	19.45009
Loc. App. T.	$16^h\ 16^m\ 33^s$
Gr. App. T.	$20\ \ 42\ \ 25$
Long.	$4^h\ 25^m\ 52^s$ $= 66°\ 28'$ W.

To change the hours to degrees by Table 45, Bowditch, at the top you find $4^h\ 25^m$ and next to it 66° 15′; in the left column the 52^s corresponds to 13′; the sum is 66° 28′, the longitude.

NOTE. — Another way of working out this sight is to change the Loc. App. Time into Local (mean) Civil Time by subtracting the Equa. of Time, and then take the difference between the Gr. (mean) Civ. T. and the Local (mean) Civ. T. The final result is the same.

CORRECTING FOR SECONDS

When looking up the log sec. Lat., log cosec *p*, etc., we must correct the log in the table for any odd seconds in the angle. For example, the log sec. 44° 43′ is 0.14838. This must be increased for the 15″ in the Lat. In the next column to the right and up on the line with 15 in the minutes column at the left we find 3. This 3 is to be added to the log sec, giving 0.14841. The other logs are corrected in the same way except that for sines, tangents and secants you add, and for cosines, cotangents and cosecants you subtract the correction.

Example 2. January 30, 1925, P.M., obs. alts. $\underline{\odot}$, 23° 58′ 30″, 23° 52′ 00″, 23° 44′ 10″, chronometer, $18\underline{^h}\ 53^m\ 40^s$, $18\underline{^h}\ 54^m\ 53^s$, $18^h\ 56^m\ 10^s$; ht. of eye, 25 ft.; I. C., 32′ 10″ on arc, 33′ 00″ off arc; C. C. -5^s; Lat. by D. R. 42° 22′ N. Find the Long. by the first of the three altitudes. The computation is shown on p. 182.

Chron.	$18^h\ 53^m\ 40^s$
C. C.	-5
Gr. C. T.	$18^h\ 53^m\ 35^s$
Equa. T.	$-13\ \ 28\ .5$
G. A. T.	$18^h\ 40^m\ 06^s.5$

Alt.	$23°\ 58'\ 30''$
Corr.	$+9\ \ 46$
h	$24°\ 08'\ 16''$

Table 46	$+9'\ 04''$
	$+\ \ 17$
I. C.	$+\ \ 25$
Corr. to alt.	$9'\ 46''$

Decl. 18^h	$-17°\ 38'.9$
Corr.	$.63$
Decl.	$-17°\ \ 38'.27$
=	$-17°\ 38'\ 16''$
p =	$107°\ 38'\ 16''$

H. D.	$0'.7$
G. T.	$0\ .9$
Corr.	$0'.63$

Equa. T. 18^h	$-13^m\ 28^s.1$
Corr.	$.36$
Equa. T.	$-13^m\ 28^s.46$

H. D.	$0^s.4$
G. T.	$0\ .9$
Corr.	$0^s.36$

h	$24°\ 08'\ 16''$
L	$42\ \ 22\ \ 00$
p	$107\ \ 38\ \ 16$
	$2)174\ \ 08\ \ 32$
s	$87°\ 04'\ 16''$
$s - h$	$62°\ 56'\ 00''$

sec.	0.13145
csc.	0.02091
cos	8.70839
sin	9.94962
hav.	8.81037
L. A. T.	$13^h\ 57^m\ 49^s$
G. A. T.	$18\ \ 40\ \ 07$
Long.	$\begin{cases} 4^h\ 42^m\ 18^s \\ = 70°\ 34'\ 30''\ \text{W.} \end{cases}$

The longitude found from the second alt. is 70° 35′ 30″; from the third it is 70° 34′ 30″ W.

TIME-SIGHT BY A STAR

When finding longitude by a star or a planet we compare the Greenwich hour angle of the star with the Local hour angle of the star in the same way that we compared the Greenwich and Local apparent times when observing on the sun. The sight on the star is taken in the same way as for the sun and the chronometer time is found from the watch time as already explained. The Local hour angle is found by solving the spherical triangle. The Greenwich hour angle is found as follows (Figs. 64 and 65):

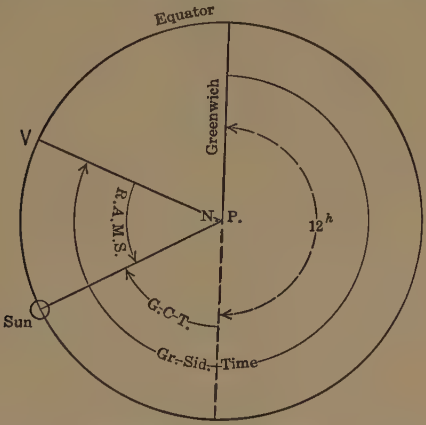

FIG. 64. Greenwich Civil and Greenwich Sidereal Time

Add the Gr. Civ. T., the "Sid. Time of 0^h, G. C. T." (or "R. A. M. S. $+12^h$"), and the correction at the foot of the page for the hours of the Gr. Civ. T. This gives the Gr. Sid. T. To obtain the Greenwich hour angle subtract the Rt. Asc. of the star from the Greenwich Sid. T.

The "Sid. Time of 0^h" or "R. A. M. S. $+12^h$" is given for every day of the year in the first table in the

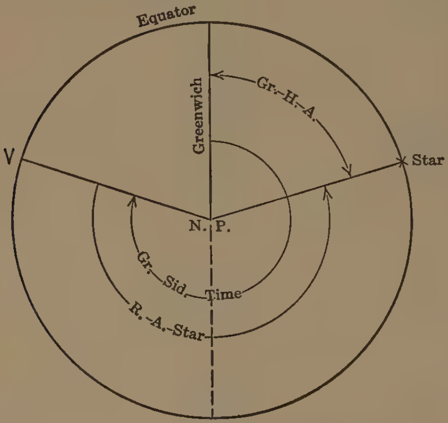

FIG. 65. Greenwich Hour Angle.

Naut. Alm. At the foot of the same page is the correction for the hours of the Gr. Civ. T.

If the spherical triangle is solved exactly as for the sun observation the result will be, not the Loc. App. Time, but the Local Hour Angle of the star. The Longitude is the difference between these two hour angles.

Watch	19^h	23^m	08^s
Chr. – Wch.	+4	31	21
Chron.	23^h	54^m	29^s
C. C.		–1	40
G. Civ. T.	23^h	52^m	49^s
R. A. M. S.			
$+12^h$	22	18	50.5
Corr.		3	55.4
	46^h	15^m	34.9^s
	24		
G. S. T.	22^h	15^m	34.9^s
R. A. *	14	12	14.6
Gr. H. A. *	8^h	03^m	$20^s.3$

Obs. Alt. *	38° 45′
Corr.	–5′ 36″
h	38° 39′ 24″

Table 46	–5′ 16″
I. C.	–20
Corr.	–5′ 36″

Decl. *	+19° 34′.4
p	70° 25′.6

h	38°	39′	24″
L	44	47	00
p	70	25	24
2)	153	51	48
s	76°	55′	54″
$s - h$	38°	16′	30″
Loc. H. A.	3^h	37^m	53^s
Gr. H. A.	8	03	20.3

Long. $\begin{cases} 4^h\ 25^m\ 27^s.3 \\ = 66°\ 21'\ 50''\ \text{W.} \end{cases}$

sec.	0.14888
csc.	0.02586
cos	9.35432
sin	9.79200
log hav.	9.32106

In taking the Hour Angle from Table 45 the angle is at the top of the page if the star is west of the meridian; if the star is east the hour angle will be found at the foot of the page, the seconds being at the right.

Example. Aug. 27, 1925 (P.M.), D. R. Lat. 44° 47′ N, D. R. Long. 66° 22′ W, obs. alt. *Arcturus* (α *Bootis*) West, = 38° 45′; watch time $7^h\ 23^m\ 08^s$ P.M.; chr. $4^h\ 31^m\ 21^s$ later than watch; C. C., $-1^m\ 40^s$; ht. of eye, 17 ft.; I. C., $-20''$. Right ascension of *Arcturus*, $14^h\ 12^m\ 14^s.6$; declination of *Arcturus*, $+19°\ 34'.4$; right ascension of mean sun $+12^h$, $22^h\ 18^m\ 50^s.5$. Find the longitude. The computation is given on p. 185.

ALTERNATIVE METHOD

Instead of changing the Gr. Civ. Time to Gr. Sid. T. and then computing the Gr. Hour Angle we may change the Local Hour Angle into the corresponding Loc. Civ. Time. The Longitude is then the difference of the two civil times. This would be done as follows:

> **Add the Loc. H. A. of the star to the Rt. Asc. of the star to obtain Loc. Sid. T. From this subtract the R. A. M. S. + 12^h, corrected for the Gr. Civ. T. (foot of page). The result is the Local Civ. T. The W. Long. is the Gr. Civ. T. minus the Loc. Civ. T.**

Applying the above rule to the example worked out on p. 185, we have,

Loc. H. A. Star	$3^h\ 37^m\ 53^s$
Rt. Asc. Star	14 12 14.6
Loc. Sid T.	$17^h\ 50^m\ 07^s.6$
Cor'd R. A. M. S. $+12^h$	22 22 45 .9
Loc. Civ. T.	$19^h\ 27^m\ 21^s.7$
Gr. Civ. T.	23 52 49 .0
Long.	$4^h\ 25^m\ 27^s.3$ $=66°\ 21'\ 50''$ W.

NOTE. — The Loc. Sid. T. is to be increased by 24^h (whenever necessary) before subtracting the R. A. M. S. $+12^h$.

WHEN TO OBSERVE FOR LONGITUDE

The principal error in the computed longitude is likely to come from the error in the D. R. Lat. When the sun or star is exactly east or west this error has no effect. It is worth while, therefore, to make the observation at such times, if it is possible; because there is always an uncertainty about the D. R. Lat. This is not the only error, however; if the sun has an altitude of less than 10° when it is E or W, it will be better to take the sight when the sun is a little higher, and avoid the refraction error.

To find the Loc. App. Time when the sun is E or W look in the table of Azimuths of the sun (H. O. No. 71), on the page marked with the degree of the Lat. and in the column marked with the Decl., or with the date; opposite the bearing which is nearest to 90° will be the required Loc. App. Time to the nearest 10 minutes. If the tables are not at hand take the altitude when the compass bearing of the sun shows that it is about true east or west.

CROSSING THE 180° MERIDIAN

When a ship changes her longitude she gains time or loses time according to whether she is traveling west or east. A navigator starting from Europe and sailing for America will have to set his clock back each day in order to have it read the local time of the ship. In traveling around the globe this change in time would amount to 24 hours and would result in the ship's calendar being one day behind at the end of the voyage. To avoid this discrepancy in dates the change in date is always made when crossing the International Date Line, which follows nearly the 180° meridian.

If a vessel is going west the calendar is set one day ahead at the midnight which is nearest the time of crossing the line. This results in one day of the week being omitted from the calendar. If the vessel is going east a day is repeated, there being two Mondays, for example, in the same week.

PROBLEMS

1. Observation for Longitude (P.M.), Aug. 8, 1925. Observed altitudes $\underline{\odot}$, 32° 06′ 30″, 31° 16′ 30″, 30° 20′ 10″; watch readings, $3^h\,36^m\,32^s$, $3^h\,41^m\,00^s$, $3^h\,46^m\,18^s$ P.M.; ht. of eye, 8 ft.; I. C. = +1′ 00″; C. C., $-1^m\,30^s$; chronometer $5^h\,01^m\,08^s$ faster than watch. Lat. by D. R., 44° 47′ N; Decl., +16° 07′.6; Equa. of time, $-5^m\,29^s.1$. Find the Longitude.

Ans. 67° 25′.6 W.

2. Observed alt. $\underline{\odot}$ July 15, 1925, 57° 37′ 50″; watch, $1^h\ 56^m\ 03^s$ P.M.; chron. $4^h\ 25^m\ 50^s$ fast of watch; ht. of eye, 36 ft.; I. C., +25″; C. C., $-1^m\ 30^s$; Decl., +21° 32′.1; Equa. of time, $-5^m\ 44^s.3$. Lat. by D. R., 44° 43′ 15″ N. Find the Longitude.

Ans. 66° 27′.5 W.

3. Observed A.M. alt. $\underline{\odot}$, 48° 40′; chron. $13^h\ 33^m\ 11^s$; C. C., $-0^m\ 01^s$; I. C., −10″; ht. of eye, 48 ft.; Decl., +23° 26′.8; Equa. of T., $-1^m\ 28^s.1$; Lat. by D. R., 44° 43′ N. Find the Longitude.

Ans. 66° 28′.5 W.

4. Corrected alt. $\underline{\odot}$, May 19, 1910 (P.M.), 44° 05′; Gr. Civ. T., $18^h\ 55^m\ 10^s$; Lat. by D. R., 42° 00′ N; Decl., +19° 42′.1; Equa. of time, $+3^m\ 43^s.4$. Find the Longitude.

Ans. 56° 56′.3 W.

5. Observed alt. $\underline{\odot}$, 15° 10′ (P.M.); ht. of eye, 25 ft.; I. C., +1′ 30″; Gr. Civ. T., $18^h\ 51^m\ 05^s$; Decl., −21° 29′.4; Equa. of T., $+11^m\ 37^s.6$; Lat. by D. R., 39° 50′ N. Find the Longitude.

Ans. 59° 57′.4 W.

6. On Feb. 1, 1925, the obs. alt. *Jupiter* is 12° 15′, bearing S and E; chron., $11^h\ 29^m\ 48^s$; C. C., -10^s; ht. of eye, 25 ft.; R. A. *Jupiter* at Gr. Civ. 0^h, $18^h\ 43^m\ 42^s.13$; var. per hour, $+2^s.303$; Decl., −22° 57′ 43″.4; var. per hour, +2″.18; Sid. time of 0^h Gr. Civ. time, $8^h\ 42^m\ 43^s.6$; Lat. by D. R., 42° 06′. Find the Longitude.

Ans. 68° 56′.6 W.

7. Observed (A.M.) alt $\underline{\odot}$, 15° 30′ (bearing S and E); ht. of eye, 20 ft.; I. C., +30″; Gr. Civ. T., $13^h\ 33^m\ 00^s$; Lat. by D. R., 42° 09′ N; Decl., −21° 15′.7. Equa. of T., $+12^m\ 00^s$. Find the Longitude.

Ans. 68° 18′ W.

8. Observation for Longitude, Jan. 30, 1925; alt. $\underline{\odot}$, 23° 31′ 30″, 23° 25′ 30″, 23° 21′ 00″; Chronometer, $18^h\ 54^m\ 20^s$, $18^h\ 55^m\ 20^s$, $18^h\ 56^m\ 05^s$; C. C., -5^s; ht. of eye, 25 ft.; I. C., +25″; Lat. by D. R., 42° 20′ N.; Decl. at 18^h, −17° 38′.9; H. D., 0′.7; Equa. of T. at 18^h, $-13^m\ 28^s.1$; H. D., $0^s.4$. Find the Longitude.

Ans. 1st alt. 70° 12′.5 W.

9. On Feb. 1, 1925, the obs. alt. *Sirius* (α *Can. Maj.*) is 10° 10′ 30″ bearing S and E; Chron., $22^h\ 34^m\ 50^s$; I. C., −10″; ht. of eye, 25 ft.; R. A. star, $6^h\ 41^m\ 51^s.3$; Decl. star, −16° 37′.0; Sid. time of Gr. Civ. 0^h, $8^h\ 42^m\ 43^s.6$; Lat. by D. R., 42° 01′ N. Find the Longitude.

Ans. 69° 00′ W.

10. Work out the longitude from the second and third altitudes given in Ex. 2, p. 181.

11. On January 31, 1925 (P.M.), obs. alt. $\underline{\odot}$, 22° 01′ 40″ bearing S and W; chron., $19^h\ 09^m\ 35^s$; C. C., -10^s; ht. of eye, 25 ft.; Lat. by D. R., 42° 20′ N; Decl. at 20^h, −17° 20′.9; H. D., 0′.7 (decl. decreasing); Equa. of T. at 20^h, $-13^m\ 38^s.1$; H. D., $0^s.4$ (Equa. T. increasing). Find the Longitude.

Ans. 69° 00′.7 W.

CHAPTER X

AZIMUTH

Azimuth Tables

THE compass error is usually found at sea by taking a bearing of the sun with the azimuth sights or by reading the position of the shadow cast by the shadow pin, thus obtaining the compass bearing of the sun; the sun's true bearing is then taken from the Azimuth Tables (either Hydrographic Office Publication No. 71, or Burdwood's Tables) for the Local Apparent Time of the observation. In taking out the sun's bearing you will need to know the latitude of the ship, the sun's declination (or the date), and the Local Apparent Time, or sun's hour angle. To find the L. A. T. you must observe the watch time when you take the compass bearing of the sun. If an observation for longitude has just been made the difference between the computed L. A. T. and the watch reading of the sight will be the error of the watch. This error applied to the watch time of the compass observation will give the true L. A. T. when the sun's bearing is required. The Lat. by D. R. is always sufficiently accurate for looking up the sun's bearing, and the declination may always be found because the G. C. T. is known.

To take out the sun's bearing from the Azimuth Table find the page marked with the degrees of the Latitude, noting whether the Lat. and Decl. are of the same or of contrary names. In the column marked with the degrees of the declination (or the date) and on the line with the Apparent Time will be found the sun's true bearing. This must be marked N if the latitude is North, but S if the latitude is South; and it must be counted toward the East if in the morning, West if in the afternoon.

INTERPOLATING FOR MINUTES

To obtain the bearing more accurately we may allow for the difference due to (1) Latitude, (2) Declination, and (3) Apparent Time. Suppose we wish to find the bearing for Lat. 40° 20′ N, Decl. 20° 10′ N, and L. A. T. $4^h\ 04^m$ P.M. ($16^h\ 04^m$). Looking in Table H. O. No. 71, for Lat. 40° and Decl. 20° (same name) and for $4^h\ 00^m$ L. A. T. we find 92° 49′. This must be marked N 92° 49′ W. For the same Decl. and App. Time but for Lat. 41° (next page) we find 93° 31′, that is, an increase of 42′ in bearing for an increase of 1° of Lat. For the extra 20′ of Lat. the change will be $\frac{20}{60} \times 42' = 14'$, to be added to the bearing for Lat. 40°. For Decl. 21° we find (same page) 91° 48′, a decrease of 61′ of bearing for an increase of 1° of Decl. The change in bearing for the extra 10′ of Decl. will be $\frac{10}{60} \times 61' = 10'$, to be subtracted from the bearing. For the L. A. T. $4^h\ 10^m$ we find bearing 91° 10′; this is a decrease of 1° 39′ or 99′ for an increase of 10^m of L. A. T. For the extra 4^m we will have $\frac{4}{10} \times 99' = 40'$, to be subtracted. The required bearing is therefore, $92° 49' + 14' - 10' - 40' = 92° 13'$. This must be marked N 92° 13′ W, or what is equivalent, S 87° 47′ W. In obtaining the bearing to correct the compass it will not usually be necessary to work closer than a degree, or a half-degree.

If a time sight has not been taken, the L. A. T. may be found by noting the chronometer time corresponding to the compass bearing. The chronometer time corrected for the chronometer error, the equation of time, and the longitude is the L. A. T.

Example 1. The computed L. A. T. from a chronometer sight is $9^h\ 25^m\ 18^s$ A.M. The watch read $9^h\ 20^m\ 10^s$ at the time of sight. The watch is therefore $5^m\ 08^s$ slow. At watch time $9^h\ 30^m\ 00^s$ the shadow pin reading is N 11° W. The Lat. is 42° N, Decl. −22° 47′. Find the compass error. Applying the watch error to $9^h\ 30^m\ 00^s$ we get $9^h\ 35^m\ 08^s$ for the L. A. T. From the Azimuth Tables for Lat. 42°, Decl. −22° 47′, L. A. T. $9^h\ 35^m\ 08^s$ we get for the bearing 145° 17′.

Sun's True Bearing	N 145° 17′ E
Comp. bear. of Sun S 11° E, or	N 169° E
Total Error of Compass	23° 43′ W

The error is W because the true bearing is less than the compass bearing, or to the left.

Example 2. Chronometer time of compass bearing $13^h\ 22^m\ 38^s$; C. C., -15^s; Equa. of time $-4^m\ 51^s$; Long. 55° 35′ 48″ W; Lat. 42° 00′ N; Decl. −22° 47′. Shadow reading 349°. Find the compass error.

Chron.	$13^h\ 22^m\ 38^s$
C. C.	-15
G. C. T.	$13^h\ 22^m\ 23^s$
Equa. T.	$-4\ \ 51$
G. A. T.	$13^h\ 17^m\ 32^s$
Long.	3 42 23 W
L. A. T.	$9^h\ 35^m\ 09^s$ at compass observation.

Sun's True Bearing	N 145° 17′ E
Compass Bearing of Sun	N 169 E
Total Error of Compass	23° 43′ W

If the variation is 27° W, then the deviation is 3° 17′ E, because the total error of the compass is less than the W deviation. The magnetic bearing is 145° 17′ + 27° = 172° 17′, which is greater than the compass bearing. This indicates error to the East.

If the magnetic bearing is to the right of the compass bearing the deviation is East; if to the left the deviation is West (see p. 24).

AZIMUTH OF A STAR

In obtaining the true bearing of a star or a planet whose declination is greater than 23°, it will be necessary to use Hydr. Office Publ. No. 120. This table is used in the same way as No. 71 except that instead of being given for hours of the L. A. T. the bearing is given for *hour angles* (H. A.), that is the number of hours either before or after the time of meridian passage.

Example. Lat. 35° N, Decl. of star 30° N. Hour angle of star $4^h\ 10^m$ E. Find the star's true bearing. From H. O. No. 120 the result is found to be 76° 47′. This is to be marked N 76° 47′ E, according to the directions at the foot of the page.

In case the Lat. and Decl. are of different names it is necessary to enter the table with the supplement of the H. A. (12^h – H. A.) and to use the supplement of the azimuth which is found in the table.

If the Hour Angle of the star is not known it may be found from the Gr. Civ. Time as follows:

Find the Greenwich Sidereal Time by adding together the Gr. Civ. T., the R. A. M. S. $+12^h$, and the correction for the Gr. Civ. T. (foot of page, N. A.); subtract from this the R. A. of the star, obtaining the Greenwich Hour Angle. Subtract from this the West longitude, obtaining finally the Local Hour Angle.

THE ALTITUDE-AZIMUTH

If the azimuth tables are not at hand the azimuth of sun or star may be found by solving the spherical triangle. In this case we need the Lat., Alt. and polar distance. So the altitude must be measured when the bearing is taken.

Add together the polar distance, the Lat. and the Alt.; divide the sum by 2 and call this the "half sum." Take the difference between the half sum and the polar dist. and call this the "remainder." Then add together the following logarithms; the secant of the Lat. the secant of the Alt., the cosine of the half sum, and the cosine of the remainder. The sum of these four logs divided by 2 is the cosine of half of the azimuth. Look up the angle corresponding to the cosine and double it.

Example. Corrected alt. of sun, 15° 23′; Lat. 42° 20′ N; Decl., −21° 16′; shadow pin, 300°. Find the azimuth.

h	15° 23	sec	0.01585		
L	42 20	sec	0.13121		
p	111 16			shadow	300°
	2)168° 59				180
s	84° 30	cos	8.98157	sun	120°
$s - p$	26 46	cos	9.95078		
			2)19.07941		
		cos	9.53970		
		½ Az.	69° 43′		
		True Azimuth	139° 26′		
		Compass Azimuth	120° 00′		
		Error	19° 26′ E		

A still simpler way is to measure the altitude with the sextant and also note the exact time.

Add together the log sine of the hour angle (H. A.), the log cosine of the Decl. and the log secant of the

alt. The sum is the log sine of the azimuth.* The H. A. is the L. A. T. or 12^h − L. A. T.

Example. L. A. T., $9^h\ 10^m\ 50^s$; Decl., −21° 16′; corrected altitude, 15° 23′. Lat., 42° 20′ N. Find the azimuth of the sun.

H. A. = $2^h\ 49^m\ 10^s$ =	42° 17′	log sin	9.82788
Decl. =	−21° 16′	log cos	9.96937
Alt. =	15° 23′	log sec	0.01585
Az. =	40° 34′	log sin	9.81310

This is evidently S 40° 34′ E because the Lat. is N and the Decl. is S. In case the sun is about east or west and the Lat. and Decl. are of the same name it may be difficult to tell whether the bearing is from the N or the S. To remove this doubt, add the log cosec. Lat. to log sin Decl., obtaining the log sin Alt. when the sun is on the prime vertical, E or W. If the observed alt. is less than this the sun is on the side toward the pole (N in N. hemisphere).

Example. Lat. 40° N, Decl. 20° N, sun's alt. 25° 30′ (P.M.).

log sin Decl.	9.53405
log csc Lat.	0.19193
log sin Alt.	9.72598
Alt. on P. V.	32° 09′

Since the obs. alt. (25° 30′) is less than this, and the Lat. is N, the bearing of the sun is N − W.

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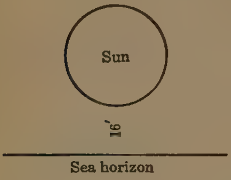
* This calculation may be performed by inspection by using Table V of H. O. Publ., No. 200.

AMPLITUDES

The compass error is often found by observing the sun's amplitude. The amplitude is the angular distance that the sun (or star) is from the E or W point, measured along the horizon. It is observed by taking the bearing when the lower edge of the sun is apparently half a diameter (16′) above the sea horizon, because the center of the sun is really on the true horizon at this time but is apparently lifted by refraction. The amplitude may be taken from Table 39, Bowditch, for the given Lat. and Decl.



Example. Lat., 30° N; compass amplitude of sun on true horizon, E 25° N; Decl., 19° N. Find compass error

By Table 39, true ampl.	E 22°.1 N
Compass ampl.	E 25 .0 N
Compass error	2°.9 E

The name of the amplitude will be the same as the name of the declination, that is, for N. Decl. the sun will be N of the E or W point; for S. Decl. it will be S of the E or W point.

If the table is not at hand the true amplitude may be found by the rule:

Add together the log secant Lat. and log sine Decl. The sum is log sine of the amplitude.

Example. Lat., 40° N; Decl., 10° N; find true amplitude when center of sun is on true horizon (setting).

log sec. 40°	0.11575
log sin 10°	9.23967
log sin ampl.	9.35542
true ampl.	13° 06′
	=W 13°.1 N

USE OF TABLE 40

If the bearing of the sun is taken when the center is on the sea horizon the observed bearing may be reduced to what it would have been if taken on the true horizon by means of the corrections in Table 40. The correction at rising in North latitudes or setting in South latitudes is applied to the **right**. At setting in North latitudes or rising in South latitudes, the correction is to the **left**.

Example. Lat., 30° N; Decl., 10° N; observed amplitude of the sun when on the sea horizon (mean of observed bearings when upper and lower limbs were in contact with the horizon), E 21° N.

Observed ampl.	E 21° N
Corr. Table 40	0°.4
Compass ampl.	E 20°.6 N
Table 39, True ampl.	E 11°.5 N
Total Compass Error	9°.1 E

If it is desired to obtain the bearing of the sun at time of sunrise or sunset, the tables at the foot of the page in H. O. Publ. No. 71 will be found very convenient.

A table of deviations may be constructed with but little trouble during a voyage by making a complete loop in the ship's track at about the time of sunset and sighting on the sun when the ship is headed on each point or on each 15° of the compass. The azimuths may be worked out either by azimuth tables or by tables of amplitudes.

PROBLEMS

1. Find the azimuth of the sun at the time of the sight in prob. 2, p. 189.

2. Find the azimuth of the sun at time of sight in prob. 8, p. 190.

3. Find the azimuth of the sun at time of sight in prob. 11, p. 190.

4. The hour angle of the sun is 34° 46′ (P.M.); Decl., −22° 45′ 50″; corrected alt., 17° 41′. Find the sun's azimuth. *Ans.* S 33° 20′ W.

CHAPTER XI

SUMNER'S METHOD

Having completed the description of the older methods of navigation, which have been known for a very long time, we will next describe Sumner's method of locating the ship. Capt. Sumner published this method in 1843 and ever since that time its use has been coming more and more into favor. The method of working out the sights now generally used is not just the same as that used by Sumner, but the principle is the same and it is generally called by his name. By the older methods the navigator finds separately his latitude and his longitude, that is, he finds what parallel he is on when he observes for latitude, and when he observes for longitude he finds what meridian he is on. Since the longitude depends upon the D. R. Lat., the computed longitude is usually uncertain. So he may be in error in both Lat. and Long. By Sumner's method the navigator finds what "position line" he is on and this line may lie in any direction whatsoever, depending upon what object he has observed. His Lat. and his Long. may both be in doubt but he knows that he is somewhere *on this position line,* although he does not know just where. However, the navigator always knows his position within a few miles, so he knows very nearly what part of the position line he must be on. By using this method he really has more definite information about the position of his vessel than he would have if he got his Lat. and Long. separately. Suppose that he got a good A.M. alt. and figured his Long., but he knew that his D. R. Lat. might be 5 miles out, and that this error might throw out his Long. by 10′. He would then conclude that he was *anywhere* within a rectangle 5′ wide in Lat. and 10′ wide in Long. But if he examined the "position line" he would learn that he is *somewhere* on the line *A–B*, and could not be in the neighborhood of *C* or *D*. Whatever the error of D. R. Lat. may be it will affect his computed longitude in such a way as to move the position *along the line AB*. The methods of finding Lat. and Long. separately are really special cases of Sumner's general method.

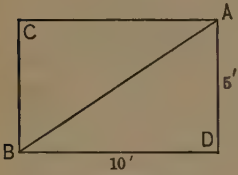


FIG. 66. Position Line *A-B*.

At any instant of time the sun must be exactly overhead at some place on the earth, and there can be only one such place. This point is often called the "sub-solar point (S. S. P.)."* The position of this point becomes known and can be laid down on the chart as soon as we know the sun's declination and the hour angle of the sun from Greenwich, that is, the Greenwich Apparent Time after noon (P.M.). The Lat. of S. S. P. is always the declination of the object observed, and the west Long.

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* If a star is observed then the star is vertically overhead at this point.

of S. S. P. is always the Greenwich hour angle of the object observed.

If a ship were exactly at the S. S. P. the sun's altitude would be exactly 90° and the zenith distance exactly 0°; in this case the ship's position would be known at once. If the ship were 60 miles, or 1°, from S. S. P. in any direction the Z. D. would be 1° and the alt. 89°. The position of the ship would not be exactly known but we would know that she is 60 miles from S. S. P., so she is on a circle whose centre is S. S. P. and whose radius is 60 miles, and this circle could be drawn on the chart. Again, if the ship were 120 miles from S. S. P. the sun's altitude would be 88°, the circle would have a radius of 120 miles and the ship would be somewhere on this larger circle. If any other navigator should measure the sun's alt. at this instant and get 88° he would be somewhere on the same circle.

If we should draw a series of circles of different radii all having S. S. P. as a center, these would be "circles of equal altitude." If we consider that circle at which the altitude = 0° (Z. D. = 90°) we see that it is the circle through all the places where the sun is rising or setting at this instant. It is also the circle which divides the illuminated half from the dark half of the earth. Anywhere within this circle the sun is visible. Beyond this circle the sun is invisible.

In Fig. 67 the steamer and the schooner both see the sun at the same alt.; they are both on the same circle and both are the same distance from S. S. P.; their latitudes and longitudes, however, are entirely different.

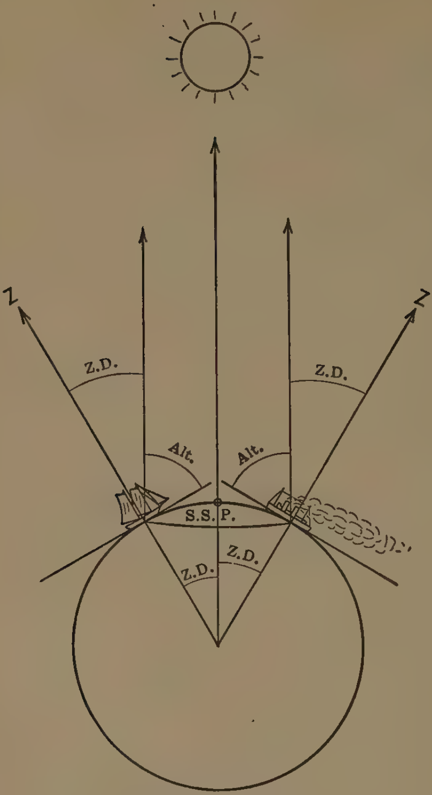


FIG. 67. Circle of Equal Altitude.

Notice that the Z. D. observed by the steamer is just equal to the angle at the center of the earth between the steamer and S. S. P., that is, the Z. D. turned into minutes is the radius (in miles) of the circle on which the steamer lies. The schooner observes the same Z. D. and is on the same circle, but in a different part of it.

The further away the ship is from the S. S. P. the larger the circles are and the flatter their curvature. If the measured altitude were 40° the Z. D. would be 50° and the distance from S. S. P. would be 3000 miles. This is so long that only a small part of the circle would come on an ordinary large-scale chart, and the portion of the circle that the ship is known to be on would look like a straight line. In fact it is usually drawn as a straight line because the difference is so small. The circle on which the vessel happens to be when the sight is taken is called a "circle of position" and is really a circle of equal altitudes. A part of this circle crossing a chart is called a "line of position" or "Sumner line." Every altitude you measure locates you on some circle of position. Such a circle could be marked on a globe by first finding the S. S. P. and then taking a radius equal to the Z. D. and striking a circle from this center. It could be drawn on a chart also by this method, although this is not usually the best way to draw the line. It can be done more accurately and conveniently by computing a point on the line, as will be explained farther on.

Since the part of the circle that we draw on a chart is practically straight and we draw it as a straight line, the line we use is really a tangent line, such as *ab*, Fig. 68. This tangent line is at right angles to the direction of the radius of the circle. This shows that the "line of position" is always at right angles to the bearing of the sun, or other object observed; that is, the bearing of the Sumner line differs 8 points or 90° from the bearing of the sun.

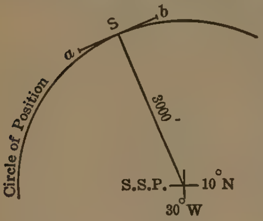


FIG. 68. Line of Position, *a-b*.

Since the navigator does not know just what part of the circle he is on he cannot really locate his ship definitely by a single sight. To locate by Lat. and Long. he must have two sights, and to locate by Sumner's method he must have two sights. He may do this either by taking sights on two different objects at the same time, or about the same time, or he may take both sights on the same object with a sufficient interval of time in between sights so that the bearing of the object will change considerably. If the sun's bearing changes say 40° then the two position lines will cut each other at an angle of 40°; it is necessary that this angle should not be very small if we wish an accurate location of the ship. The nearer to 90° the lines cut the better the location. If the ship does not change her position between these two sights their intersection on the chart shows the true position at the time of observation. If she does change her position between sights then the radius of the first circle of position must be changed accordingly; in other words, the first line of position must be moved to correspond with the run of the vessel. The method of doing this will be explained later on.

In Fig. 69 *A* is the position of S. S. P. when the Greenwich Apparent Time is 1^h P.M. (or 13^h) and the declination is 20° N. The alt. is 70° so the Z. D., or radius of the circle, is 20° or 1200 miles. The ship is somewhere on this circle at 1^h P.M. If the sun's alt. is again observed and found to be 60° at 4^h P.M. (16^h) when the S. S. P. is at *B* the ship is then on the second circle, whose radius is 30°, or 1800 miles. The ship must then be at one of the two intersections, *S* or *T*. Since the true position will always be known within a few miles there will not be any

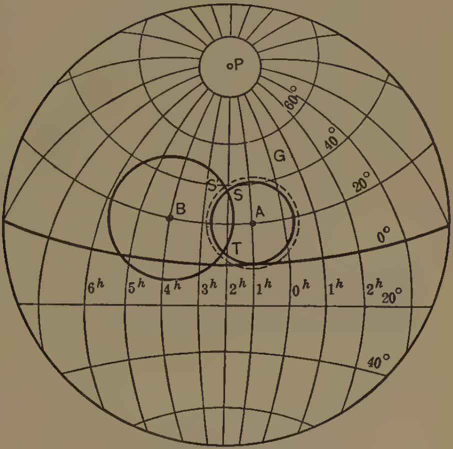


FIG. 69. Sumner's Method.

doubt as to which of these two points is the true one. If, however, the ship has sailed 60 miles away from the sun during the interval between sights the first circle must be corrected by increasing its radius 1°. This gives the dotted circle, radius 21°. In this case the true position of the ship at 4^h P.M. is at S', the intersection of the dotted circle with the circle whose center is at B.

If you observe an altitude and then with some latitude which you suppose to be about right (your D. R. Lat.) you calculate a longitude, you will have a point which is somewhere on the line of position. It may not be the position of the vessel but it is on the position line passing through the vessel because you use the same altitude. If this point is laid down on the chart and a line drawn through it at *right angles* to the bearing of the sun this will be the position line on which the ship was located when the sight was taken. If your D. R. Lat. was in error this moves your position along this line, but never off of the line.

In calculating the observation we may use several methods. *First*, we may assume a Lat. a little north of where we think we are and calculate a Long.; then assuming a Lat. south of our true position, we calculate another Long. Laying down these two positions on the chart and connecting them by a straight line we have the line of position. The ship is somewhere on this line. This is the method originally used by Sumner. *Second*, we may take the D. R. Lat. and calculate a Long. and lay down this position on the chart. Through this point we draw a line whose bearing is at right angles to the bearing of the sun. This is the line of position. *Third,* we may assume a position, both the Lat. and Long., and calculate the altitude the sun would have at that place. This will usually differ from the altitude observed at the ship. This difference in altitude is to be laid off (in miles) from the assumed position, either toward the sun or away from the sun, and a position line drawn through this new point at right angles to the sun's bearing. This is the true position line. This last method is the one known as Marcq Saint Hilaire's.

When two position lines can be laid down their intersection point is the ship's true position, provided both lines correspond to the same instant of time, because the ship is on both lines at once. The position of the ship may be found either by calculating the Lat. and Long. of the intersection point or by laying down the lines on the chart and reading off the Lat. and Long. from the margin of the chart. The latter method is quicker, and, with the right kind of charts, is as accurate as the altitude itself.

Remember that in all these methods you are just as much dependent upon the chronometer as when getting longitude by the "chronometer sight" method. The longitude found from Sumner lines can be only as accurate as the Greenwich time given by the chronometer.

POSITION LINE FROM THE "CHRONOMETER SIGHT"

When the object observed is just about east or west, that is, on the prime vertical, there is probably no better way to work up the sight than by the method already used for getting longitude. After the longitude is computed the position is laid down and the Sumner line drawn through this point. Remember that the bearing of the position line is always at right angles to the bearing of the sun. To change this bearing of the sun to the bearing of the line add or subtract 90° if the bearing is expressed in the 360° system; if given in the quadrant system change one letter and take the number of degrees from 90°.

As an illustration of this method let us take the observation worked out on p. 182, but instead of using the D. R. Lat. let us assume a slightly different Lat., say 42° 15′ N. Working out the longitude and the sun's bearing we find them to be as follows: Long. 70° 18′ 45″ W; Az. of the sun by tables N 148° 55 W. The bearing of the position line is therefore N 58° 55′ W.

Laying down the position on the chart (*A*, Fig. 70) and drawing the position line in the direction N 58° 55′ W we have the line *AB* shown in the figure. Notice that this line passes through the position *B*, 42° 22′ N, 70° 34′ 30″ W, which is the one obtained by the original computation on p. 182. The line also passes through the true position of the ship whatever its Lat. may be.

ALLOWING FOR RUN

When two observations are to be made on the same body to determine the ship's position, it is necessary to wait until the body has changed its bearing by at least 2 points, or nearly 30°, before making the second observation; otherwise the two position lines will cut at a very acute angle and the position will not be definite and accurate. During the interval between sights the ship will change her position, and this makes it necessary to

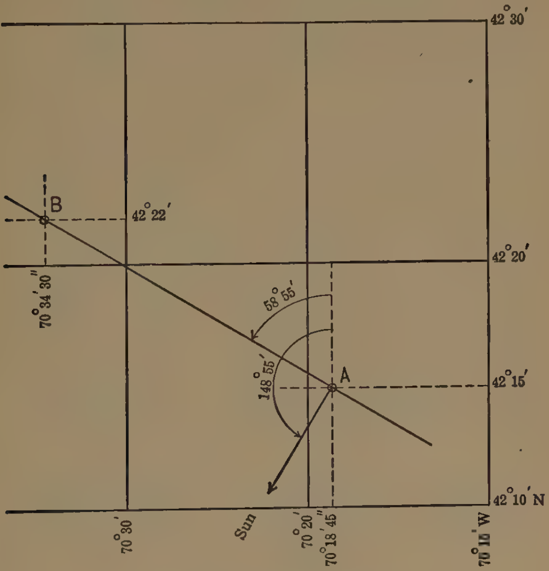


FIG. 70. Line of Position.

move the first Sumner line to a position that corresponds to the time of the second sight. This is easily done by selecting any point on the first position line, usually the point computed, and drawing from it a line which runs in the direction of the ship's course and whose length is the distance run. The end of this line is a point on the "corrected" Sumner line. If a new line be drawn through this extremity and parallel to the original position line this will be the "corrected" position line and will pass through the ship's position at the time of the second observation. The point where this corrected position line cuts the second position line is the ship's position at the time of the second sight and is called the "Fix."

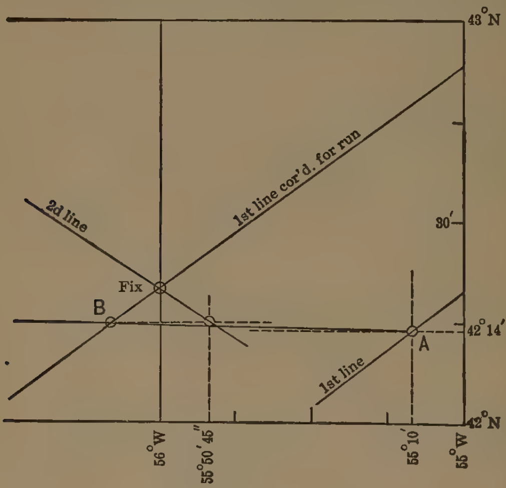


FIG. 71. Position by two Sumner Lines.

Example. Jan. 4, 1910, at chron. time $13^h\ 12^m\ 48^s$ the obs. alt. $\underline{\odot}$ was 15° 53′ 30″, bearing S and E; I. C., 0″; ht. of eye, 36 ft.; C. C., -15^s; Equa. of T., $-4^m\ 51^s$; Lat. by D. R., 42° 14′ N. Computing the longitude we get 55° 10′ W. By tables, the sun's true bearing is S 36° 26′ E (or 143° 34′). See page 214 for calculation. The position line has the bearing N 53° 34′ E (or 53° 34′) as shown in Fig. 71. Between this sight and the P.M. sight the ship runs N 89° W (271°) a distance of 45 miles. From the known point *A*, on the position line, we draw a line running N 89° W, 45 miles, which gives point *B*, whose Lat. is 42° 14′.8 N. Through *B* we draw a line parallel to the first position line, giving the position line we should have found if the ship had been in the position of the P.M. sight at the time when the A.M. sight was taken. This is marked "1st line corrected for run."

At chron. time $18^h\ 05^m\ 46^s$ the sun's alt. was 17° 33′ 30″ bearing S and W; I. C., 0″; Ht. of eye, 36 ft.; C. C., -15^s; Equa. of T., $-4^m\ 57^s$. Using the Lat. 42° 14′.8 N the resulting longitude is 55° 50′ 45″ W, and the sun's true bearing is S 33° 03′ W (or 213° 03′). See page 215 for calculations. The position line for this P.M. sight has a bearing N 56° 57′ W (or 303° 03′) and is marked "2nd line" in Fig. 71. The lines cross at Lat. 42° 20′ N, Long. 56° 01′ W, which is the true position of the ship at the time of the P.M. sight.

FIRST OBSERVATION

Chron.	$13^h\ 12^m\ 48^s$
C. C.	-15
Gr. Civ. T.	$13^h\ 12^m\ 33^s$
Equa. T.	$-4\ \ 51$
Gr. App. T.	$13^h\ 07^m\ 42^s$
h	16° 00′ 43″
L	42 14
p	112 47 04
2)	171° 01′ 47″
s	85° 30′ 53″
$s-h$	69° 30′ 10″

Alt. ⊙	15° 53′ 30″
Corr.	+7 13
h	16° 00′ 43″
Table 46	+6′ 55″
	+18
Corr.	+7′ 13″
sec	0.13053
cosec	0.03528
cos	8.89322
sin	9.97160
log hav.	9.03063
	$2^h\ 32^m\ 58^s$
L. A. T.	$9^h\ 27^m\ 02^s$
G. A. T.	13 07 42
Long.	$3^h\ 40^m\ 40^s$ 55° 10′ W.

Cor'd Decl.	−22° 47′ 04″
p	112° 47′ 04″
Cor'd Equa. T.	$-4^m\ 51^s$
Sun's Az.	S 36° 26′ E
Long. factor	1.82

SECOND OBSERVATION

Chron.	$18^h\ 05^m\ 46^s$
C. C.	-15
Gr. Civ. T.	$18^h\ 05^m\ 31^s$
Equa. T.	$-4\ \ 57$
Gr. App. T.	$18^h\ 00^m\ 34^s$

h	17° 41′ 02″
L	42 14 48
p	112 45 50
2)	172° 41′ 40″
s	86° 20′ 50″
$s - h$	68° 39′ 48″

Alt. ⊙	17° 33′ 30″
Corr.	+7 32
h	17° 41′ 02″

Table 46	+7′ 14″
	+18
Corr.	+7′ 32″

sec	0.13062
cosec	0.03521
cos	8.80421
sin	9.96916
log hav.	8.93920
	$2^h\ 17^m\ 11^s$
L. A. T.	$14^h\ 17^m\ 11^s$
G. A. T.	18 00 34
Long.	$3^h\ 43^m\ 23^s$ 55° 50′ 45″ W.

Cor'd Decl.	−22° 45′ 50″
p	112° 45′ 50″
Cor'd Equa. T.	$-4^m\ 57^s$
Sun's Az.	S. 33° 03′ W.
Long. factor	2.07

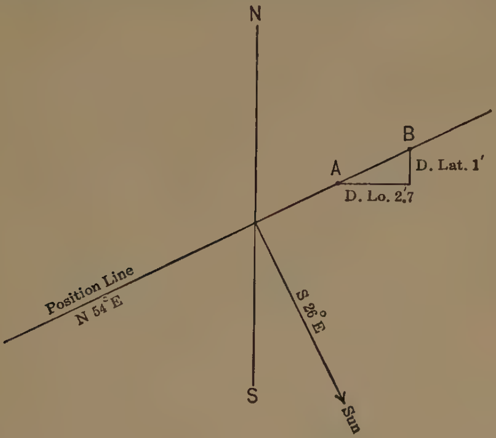
The quickest and easiest way to lay down these position lines is to use the Position Plotting Sheets. The latitudes must agree with those printed on the side margin of the chart, so be sure to get the right chart for your latitude; the longitude degrees are all of the same length and therefore the meridians may be numbered for any longitude according to the position of the ship. The bearing of the position line may be laid off by means of the compass rose and is 90° greater than the bearing of the sun. The run of the ship is laid off by means of the compass rose and the distance in miles is taken from the scale of miles marked on a meridian. Do not use the minutes of longitude for miles.

POSITION OF THE "FIX" BY COMPUTATION

The position of the ship may be computed if desired, although the charts will usually give the position as closely as it is needed. In computing the position we use the "Longitude Factors," Table 47.

The longitude factor is the change in Long. caused by a change of one minute of Lat. and may be computed by multiplying the secant Lat. by cotangent Az. (add log sec Lat. to log cot Az. to get log factor). These factors may be looked up directly in Table 47, Bowditch. If the factor is 2.70 it means that when the point is moved along the position line (from *A* to *B*) so as to change its Lat. 1′ then its Long. will change 2′.7, as will be understood by referring to the diagram (p. 217). In this case an increase of 1′ Lat. causes a decrease of 2′.7 Long. because the position line bears N and E.

Working out the first observation given on p. 214, using D. R. Lat. 42° 14′ N, we obtain Long. 55° 10′ W;



sun's bearing, S 36° 26′ E. From Table 47 we find the Long. factor to be 1.82. This factor shows that if we increase our Lat. one minute the Long. will decrease 1′.82. Before calculating the second longitude we must correct the Lat. for run.

Course	Dist.	N	W	D. Lo.
N 89° W	45	0.8	45.0	60.5

Lat. by D. R.	42° 14′ N	Long. by Comp.	55° 10′ W
Diff. Lat.	0 .8 N	D. Lo.	1 00 .5 W
Cor'd Lat.	42° 14′.8 N	Cor'd Long.	56° 10′.5 W

Using this corrected Lat. we find the second longitude to be 55° 50′ 45″ W; the sun's bearing is S 33° 03′ W. The Long. factor is 2.07. This factor shows that if we increase the Lat. one minute the Long. will increase 2′.07.

The corrections to the Lat. and Long. may now be found from the discrepancy in the two longitudes.

Second Long.	55° 50′ 45″ W	
First Long. cor'd for run	56 10 30 W	
Discrepancy in Long.	19′ 45″	= 19′.75

If we divide this by the sum of the two longitude factors we get the correction to the Lat. used for the second observation.

$$19'.75 \div (1.82 + 2.07) = 5'.1$$

The Lat. of "Fix" is therefore 42° 14′.8 + 5′.1 = 42° 19′.9 N. To correct the longitudes multiply each Long. factor by the Lat. correction and apply the results to the Long. The two results should agree.

$$\begin{array}{r} 1.82 \\ \underline{5.1} \\ 1\ 82 \\ \underline{910} \\ 9'.282 \end{array} \qquad\qquad \begin{array}{r} 2.07 \\ \underline{5.1} \\ 2\ 07 \\ \underline{103\ 5} \\ 10'.557 \end{array}$$

Long.	56° 10′.5	Long.	55° 50′.75
	9 .3		10 .55
Long. of "Fix"	56° 01′.2	Long. of "Fix"	56° 01′.3

The position of the Fix is therefore Lat. 42° 19′.9 N, Long. 56° 01′.2 W.

The relation of these corrections is shown in the triangle in Fig. 72.

If the object observed is on the same side of the meridian at both sights we must use the difference of the Long. factors instead of the sum. (See Fig. 73.)

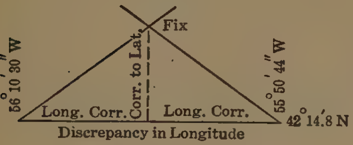


FIG. 72. Position by Computation.

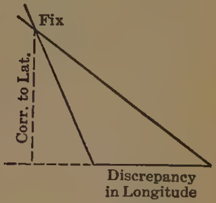


FIG. 73. Two P.M. Sights.

THE METHOD OF MARCQ SAINT HILAIRE

In Saint Hilaire's method we make the same observation and solve the same triangle, only instead of assuming a Lat., and then with polar distance and altitude finding the L. A. T. (or hour angle), we assume *both* a Lat. and a Long. (that is equivalent to assuming L. A. T.) and with the polar distance we *calculate an altitude*. If the ship happened to be at the place assumed, or anywhere else on the Sumner line through that place, this calculated altitude would come out the same as the observed altitude. If the calculated altitude is different from the observed altitude it shows that the ship was not on that position line and that the ship's distance in miles from that position line is equal to the difference between the two altitudes. This altitude difference is to be measured directly toward or directly away from the sun. It will be seen that this is a method of "trial and error." It is the best way to work up sights, when calculation is used, except when the sun is just about east or west. In that case the "chronometer sight" or "time sight" method is the best.

One advantage of this method is that all sights are worked up in exactly the same way no matter where the object may be; ex-meridian, chronometer sights or sights somewhere in between, are all worked by the same rule, as follows:

> **Assume a Lat. and a Long. (take the D. R. Position), and from the chronometer time compute the Local Apparent Time (L. A. T.) by applying the C. C., the Equa. of T., and the Longitude. Then add the log hav L. A. T., log cos Lat., log cos Decl. The result is the log hav of an angle θ. Take out the nat hav θ (θ itself is not needed). Add to the nat hav θ the nat hav Lat. ~ Decl. The result is nat hav Zenith Dist. To find Lat. ~ Decl. take the difference between Lat. and Decl. if they are of the same name, but take the sum if of different names. The calculated altitude is the difference between 90° and the Zenith Distance. The difference between the observed alt. (h_0) and the calculated alt. (h_c) is the altitude difference to be laid off. If h_0 is greater than h_c move the point directly toward the sun; if less move it away from the sun.**

The process may be most easily understood by following an example. Let us use the same observation (p.

214), taking as the assumed point the D. R. Lat. 42° 14′ N and a longitude of 55° 00′ W, which we may suppose was the D. R. Long. at the time of the A.M. sight. Calculating the altitude corresponding to this position we obtain 16° 05′.2 as shown on p. 222. The altitude difference is 4.5 miles, to be laid off *away from* the sun. At the assumed point the altitude if observed would have been 16° 05′.2; since the actual observed altitude was 16° 00′.7 the ship must have been farther away from the sun by 4.5 miles, because the farther away the ship is from the S. S. P. the smaller is the sun's altitude.

The Loc. App. Time (L. A. T.) used in calculating the altitude is really the hour angle of the sun from noon, that is, if the time is $9^h\ 27^m\ 42^s$ the sun is $2^h\ 32^m\ 18^s$ from noon and we take the log hav of this time from Table 45.

FIRST OBSERVATION

Chron.	$13^h\ 12^m\ 48^s$
C. C.	-15
Gr. Civ. T.	$13^h\ 12^m\ 33^s$
Equa. T.	$-4\ \ 51$
Gr. App. T.	$13^h\ 07^m\ 42^s$
Long.	$3\ \ 40\ \ 00$
Loc. App. T.	$9^h\ \ 27^m\ 42^s$
or $2^h\ 32^m\ 18^s$ from noon	

Alt. ☉	15° 53′ 30″
Corr.	+7 13
h_0	16° 00′ 43″
Table 46	+6 55
	18
Corr. to alt.	+7′ 13″

Cor'd Decl.	−22° 47′ 04″
Cor'd Eq. T.	$-4^m\ 51^s$
Sun's Az.	S. 36° 26′ E.

L. A. T.	$2^h\ 32^m\ 18^s$
Lat.	42° 14′ N.
Decl.	−22° 47′ 04″ S.
$L \sim D$	65° 01′ 04″
Z. D.	73° 54′.8
Calc., h_c	16° 05′.2
Obs'd, h_0	16° 00′.7
Alt. diff.	4′.5, away from.

log hav	9.02693
log cos	9.86947
log cos	9.96471
θ log hav	8.86111
θ nat hav	0.07263
nat hav	0.28883
nat hav	0.36146

SECOND OBSERVATION

Chron.	$18^h\ 05^m\ 46^s$
C. C.	-15
Gr. Civ. T.	$18^h\ 05^m\ 31^s$
Equa. T.	$-4\ \ 57$
Gr. App. T.	$18^h\ 00^m\ 34^s$
Long.	$3\ \ 44\ \ 16.4$
L. A. T.	$14^h\ 16^m\ 17^s.6$
or	$2^h\ 16^m\ 17^s.6$

Alt. ☉	$17^\circ\ 33'\ 30''$
Corr.	$+7\ \ 32$
h_0	$17^\circ\ 41'\ 02''$
Table 46	$+7'\ 14''$
	$+18$
Corr.	$+7'\ 32''$

Cor'd Decl.	$-22^\circ\ 45'\ 50''$
Cor'd Eq. T.	$-4^m\ 57^s$
Sun's Az.	S. $33^\circ\ 03'$ W.

L. A. T.	$2^h\ 16^m\ 17^s.6$
Lat.	$42^\circ\ 18'.4$ N
Decl.	$22^\circ\ 45'.8$ S
$L \sim D$	$65^\circ\ 04'.0$
Z. D.	$72^\circ\ 16'.3$
Calc. h_c	$17^\circ\ 43'.7$
Obs. h_0	$17^\circ\ 41'.0$
Alt. diff.	$2'.7$, away from.

log hav	8.93369
log cos	9.86897
log cos	9.96478
θ log hav	8.76744
θ nat hav	0.05854
nat hav	0.28922
nat hav	0.34776

Laying down the position 42° 14′ N, 55° 00′ W, and drawing a line having the bearing of the sun (S 36° 26′ E) we measure off 4.5 miles away from the sun and then draw a line through this new point, *A*, at right angles to the sun, or N 53° 34′ E, obtaining the line *AB*, Fig. 74.

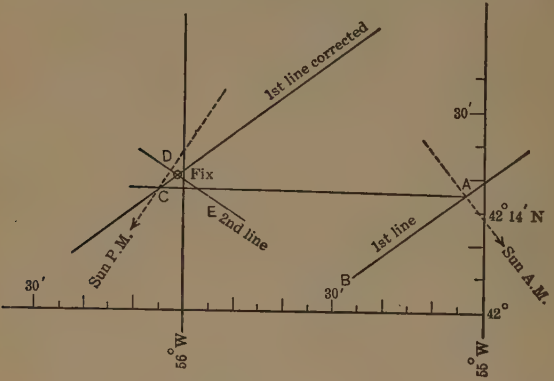


FIG. 74. Position by Saint Hilaire's Method.

This is the same line as was found before on Fig. 71, p. 212. This line must now be moved to allow for the run of the ship just as was done before. Moving point *A* N 89° W 45 miles gives point *C*. The Lat. and Long. of this are Lat. 42° 18′.4 N, and Long. 56° 04′.1 W.

The second line is found in the same way. For an assumed position we may use point *C*, Lat. 42° 18′.4 N, Long. 56° 04′.1 W. Using the data given on p. 215 for the second observation we get (on p. 223) for the calculated altitude (h_c) 17° 43′.7. This is 2′.7 more than the observed alt. The point *C* must therefore be moved 2.7 miles away from the sun to get a point *D* on the second (P.M.) line. This gives the position line *DE*, Fig. 74. The Fix is at the intersection of these two lines and gives the Lat. 42° 20′ N, and Long. 56° 01′ W.

The position of the Fix may be found by calculation instead of by chart if preferred. When the point is moved toward the sun or away from the sun we use the traverse tables to find the difference in Lat. and Long. When the point is moved along a position line the Long. factor is used for this purpose. To compute the Lat. and Long. of the Fix in the preceding example we start with the D. R. position 42° 14′ N, 55° 00′ W, and then find point *A* by working a traverse on the line N 36° 26′ W 4.5 miles, as follows:

Course	Dist.	N	W	D. Lo.
N 36° 26′ W	4.5	3.6	2.7	3′.6

D. R. Lat.	42° 14′ N	D. R. Long.	55° 00′ W
D. Lat.	3 .6 N	D. Lo.	3 .6 W
Lat. A.	42° 17′.6 N	Long. A.	55° 03′.6 W

To move *A* to *C* so as to allow for the run of the ship we use the same traverse that was given on p. 217; this shows that the position should be moved 0′.8 N, 60′.5 W.

Lat *A*	42° 17′.6 N	Long. *A*	55° 03′.6 W
	0 .8 N		1 00 .5 W
Lat. *C*	42° 18′.4 N	Long. *C*	56° 04′.1 W

In order to fix the second position line we start at *C* and calculate a traverse running N 33° 03′ E, 2.7 miles, as shown below:

Course	Dist.	N	E	D. Lo.
N 33° 03′ E	2.7	2.3	1.5	2′.0

Lat. *C*	42° 18′.4 N		Long. *C*	56° 04′.1 W
Dif. Lat.	2 .3 N		Dif. Lo.	2 .0 E
Lat. *D*	42° 20′.7 N		Long. *D*	56° 02′.1 W

We next move down along the second position line until we reach *F*, a point in the same latitude as *C*. The Lat. of *D* is 2′.3 greater than the Lat. of *C*. The Long. factor of this line shows that for every minute we go south we must go east 2′.07 in Long.; this would be 2′.3 × 2′.07 or 4′.8 in all. The Long. of *F* is therefore 56° 02′.1 − 4′.8 = 55° 57′.3 W. The positions of these points are shown in Fig. 75.

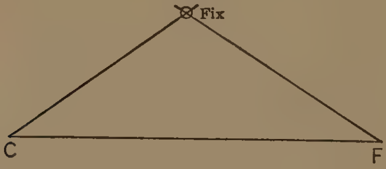


FIG. 75.

The rest of the computation is like that shown on p. 218. The discrepancy in the longitude of *C* and *F* is first found.

Long. *C*	56° 04′.1 W
Long. *F*	55 57 .3 W
Discrepancy	6′.8

Dividing this discrepancy by the sum of the two Long. factors (3.89) we have 1′.74 as the correction to the Lat. of *C*.

3.89)6′.80(1′.74
389
2910
2723
1870
1556

Lat. *C*	42° 18′.4 N
Corr.	1. 7 N
Lat. of Fix	42° 20′.1

Correcting the longitudes separately we find:

1.82	2.07
1.74	1.74
7 28	8 28
1 274	1 449
182	207
3.1668	3.6018

Long. *C*	56° 04′.1 W	Long. *F*	55° 57′.3 W
	3 .2 E		3 .6 W
Long. of Fix	56° 00′.9	Long. of Fix	56° 00′.9 W

STAR SIGHTS — SAINT HILAIRE'S METHOD

To illustrate Saint Hilaire's method when applied to an observation on a star take the sight on the star *Antares* (α *Scorpii*), observed altitude 16° 34′ (bearing S and W); chron. time, $23^h\ 52^m\ 51^s$; C. C., $-1^m\ 40^s$; ht. of eye, 17 ft.; I. C., −20″. Decl. of *Antares*, −26° 15′.1; Rt. Ascen. *Antares*, $16^h\ 24^m\ 22^s.6$. Lat. by D. R., 44° 47′ N; Long. by D. R., 66° 22′ W.

This is worked like the sun observation except that the Local Hour Angle of the star must be found by subtracting the West Longitude of the ship from the Greenwich Hour Angle of the star (p. 184). The calculations for this sight are on p. 229.

Chron. T.	$23^h\ 52^m\ 51^s$
C. C.	$-1\ \ 40$
Gr. Civ. T.	$23^h\ 51^m\ 11^s$
R. A. M. S. $+12^h$	22 18 37 .8
Corr. for G. T.	3 55 .1
Gr. Sid. T.	$22^h\ 13^m\ 43^s.9$
Rt. Asc. Star	16 24 22 .6
Gr. H. A.	$5^h\ 49^m\ 21^s.3$
Long.	4 25 28 .0
Local H. A.	$1^h\ 23^m\ 53^s.3$

Obs alt.	16° 34′
Corr.	−7 36″
h	16° 26′ 24″

Table 46	−7′ 16″
I. C.	−20
Corr.	−7′ 36″

Loc. H. A.	$1^h\ 23^m\ 53^s.3$
Lat.	44° 47′ N
Decl.	26° 15′.1 S.

log hav	8.52012
log cos	9.85112
log cos	9.95272
θ log hav	8.32396
θ nat hav	0.02109
nat hav	0.33750
	0.35859

$L \sim D$	71° 02′.1
Z. D.	73° 34′.2
Calc. *h*	16° 25′.8
Obs. *h*	16° 26′.4
Alt. diff.	0′.6, toward.

The bearing is S 19° ½ W

Long. factor is 3.96

For the second observation take the sight on *Arcturus* (*α Boötis*), obs. alt., 38° 45′; chron. time, $23^h\ 54^m\ 29^s$; C. C., $-1^m\ 40^s$; ht. of eye, 17 ft.; I. C., $-20''$. Decl. of *Arcturus*, $+19°\ 36'.7$; Rt. Ascen. *Arcturus*, $14^h\ 11^m\ 54^s.6$; Lat. by D. R., 44° 47′ N; Long. by D. R., 66° 22′ W.

The calculations for this sight are on p. 231.

Chron. T.	$23^h\ 54^m\ 29^s$
C. C.	$-1\ \ 40$
Gr. Civ. T.	$23^h\ 52^m\ 49^s$
R. A. M. S. $+12^h$	22 18 37 .8
Corr. for G. T.	3 55 .1
Gr. Sid. T.	$22^h\ 15^m\ 21^s.9$
Rt. Asc. Star	14 11 54 .6
Gr. H. A.	$8^h\ 03^m\ 27^s.3$
Long.	4 25 28 .0
Loc. H. A.	$3^h\ 37^m\ 59^s.3$

Obs. alt.	38° 45′
Corr.	−5 36″
h	38° 39′ 24″

Table 46	−5′ 16″
I. C.	−20
	−5′ 36″

Loc. H. A.	$3^h\ 37^m\ 59^s.3$
Lat.	44° 47′ N
Decl.	19° 36′.7 N

log hav	9.32145
log cos	9.85112
log cos	9.97405
θ log hav	9.14662
θ nat hav	0.14016
nat hav	0.04748
nat hav	0.18764

$L \sim D$	25° 10′.3
Z. D.	51° 20′.3
Calc., h_c	38° 39′.6
Obs., h_o	38° 39′.4
Alt. diff.	0′.2, from.

The bearing is S 79° W

Long. factor 0.27

Laying down the position 44° 47′ N, 66° 22′ W and moving the point 0.6 mile S 19° ½ W (toward *Antares*) and drawing a line at right angles we have the first position line, *AB*, Fig. 76. Laying down the same position 44° 47′ N, 66° 22′ W, and moving the point N 79° E 0.2 mile (from *Arcturus*), and drawing a line at right angles we have the second position line, *CD*. The intersection is the position of the Fix (1).

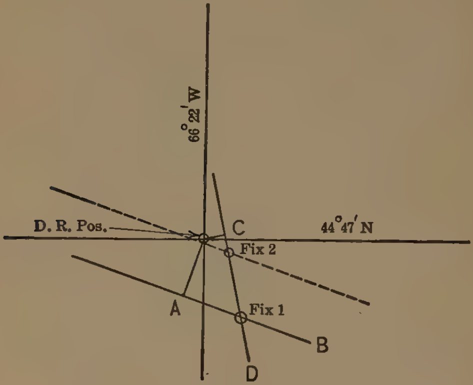


FIG. 76.

The change in the position of the vessel during the $1^m\ 38^s$ which elapsed between sights could be allowed for by moving the first line a corresponding amount, which in this case would be NE, 0′.6. Moving the first line by this amount we find the position to be at Fix 2 as shown in Fig. 76. The Lat. and Long. of the Fix may of course be calculated exactly as for the sun observations as described on pp. 225–7.

Whenever the two sights are taken at different times the position of the Fix is uncertain on account of the run between sights. If the two altitudes can be taken at the same instant then we have the position of the ship at once, with no error due to run. To do this would require two observers and two sextants. One observer may, however, obtain the same result by taking an altitude of the first object with chronometer time, then an altitude of the second object and the time, and finally another altitude of the first object with the time. By interpolation between the two altitudes on the first object it is possible to find closely the altitude the first object had at the time when the second one was sighted; these two may then be worked as simultaneous sights.

POSITION LINES BY TABLES

Table H. O. No. 201

The Hydrographic Office now publishes two tables by means of which Sumner lines can be laid down without solving the spherical triangle. By making use of triangles already solved we may find the position line by an inspection of the tables. In H. O. No. 201 we have given the altitude and the azimuth for every whole degree of latitude and every whole degree of declination, and for every 10^m of hour angle. We can always find in the table the parts of a triangle that are very nearly the same as the parts of the triangle we wish to solve.

In the example on pages 213 and 221 we found the same position line, no matter whether we started from Lat. 42° 14′ N, Long. 55° 10′ W or from Lat. 42° 14′ N, Long. 55° 00′ W. So it would make no difference in the final line if we assumed a whole degree for the Latitude and assumed some longitude which made the L. A. T. (hour angle) come out an even 10^m. Then there would be left only the Declination. We cannot change this so we would have to interpolate on account of the minutes of the Declination.

For example, if we wish to lay down on the plotting sheet the position line for the observation on Jan. 4, 1910 (see p. 212), we should have Lat. 42° 14′ N, Long. 55° 10′, Decl. −22° 47′ 04″. From the chron. time $13^h\ 12^m\ 48^s$, C. C., -15^s, and Equa. of Time, $-4^m\ 51^s$, we find that the L. A. T. is $9^h\ 27^m\ 02^s$ as follows:

Chron.	$13^h\ 12^m\ 48^s$
C. C.	-15
G. C. T.	$13^h\ 12^m\ 33^s$
Equa. T.	$-4\ \ 51$
Gr. App. T.	$13^h\ 07^m\ 42^s$
Long.	$3\ \ 40\ \ 40$
L. A. T.	$9^h\ 27^m\ 02^s$

In order to make this L. A. T. come out an even 10^m we may change our longitude. The nearest 10^m would be $9^h\ 30^m$; if we work back from this we find that the longitude at which the L. A. T. is $9^h\ 30^m$ (or $2^h\ 30^m$ from noon) is 54° 25′.5 W, as shown on the following page.

Gr. App. T.	$13^h\ 07^m\ 42^s$
L. A. T.	$9\ \ 30$
Long.	$3^h\ 37^m\ 42^s$
	$= 54°\ 25'.5$ W, assumed Long.

In using the table we must therefore use Lat. 42° N, Long. 54° 25′.5 W (or L. A. T. $2^h\ 30^m$ from noon) because these numbers will be found in the table. On p. 437 (H. O. No. 201) we find under Lat. 42°, Decl. contrary name to Lat., the following numbers, slightly rearranged.

Lat. 42°

Hour Angle	Decl. 22°		Decl. 23°	
	Alt.	Az.	Alt.	Az.
$2^h\ 40^m$	16° 05′.5	141°.7	15° 13′.4	142°.2
2 30	17° 13′.1	143°.8	16° 20′.1	144°.3
2 20	18° 17′.2	146°.0	17° 23′.6	146°.4

Only the middle line is needed; the others are given merely to show the arrangement of this table. For Lat. 42°, L. A. T. $2^h\ 30^m$, and Decl. 23° the alt. is 16° 20′.1 and the Az. is 144°.3. To allow for the minutes of declination notice that 22° 47′ 04″ is 12′ 56″ or 12′.9 less than 23°, and 22° is 60′ less than 23°. We then take 12′.9 sixtieths of the difference. The difference is, for the alt.,

for 22°	alt.	17° 13′.1
for 23°		16 20 .1
diff.		53′.0

$$\frac{12.9}{60} \times 53' = 11'.4$$

which is the amount to add to 16° 20′.1.

16° 20′.1 + 11′.4 = 16° 31′.5, the calculated alt. We could, of course, work from the alt. for Decl. 22°. In this case we must subtract from 17° 13′.1 a correction of 47.1 sixtieths of 53′, which gives

$$\frac{47.1}{60} \times 53' = 41'.6$$

17° 13′.1 − 41′.6 = 16° 31′.5, the calculated alt. For the Az. we get

for 23°	144°.3
for 22°	143 .8
diff.	0 .5

$$\frac{12.9}{60} \times 0.5 = 0^\circ.1$$

$$144^\circ.3 - 0^\circ.1 = 144^\circ.2, \text{ Az.}$$

For laying down the position line we now have

Lat.	42° N
Long.	54° 25′.5 W
Calc. alt.	16° 31′.5
Az.	N 144°.2 E

The difference between this calculated alt. and the observed alt. is

Calc. alt.	16° 31′.5
Obs. alt.	16 00 .7
Alt. diff.	30′.8, away from sun.

Laying down this position and drawing a line in the direction N 144°.2 E (that is S 35°.8 E) and measuring

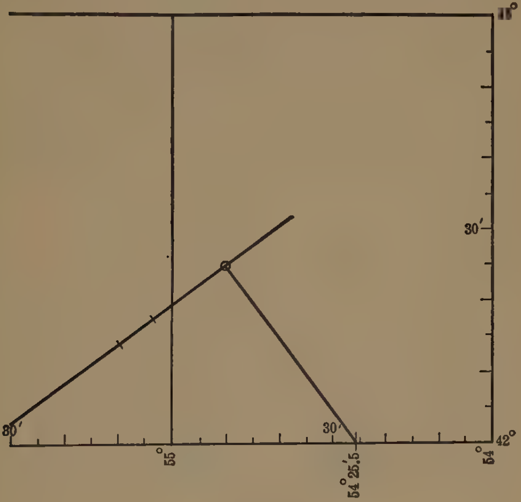


FIG. 77.

off 30′.8 away from the sun we have a point on the position line (Fig. 77). Drawing this line in the direction

N 54°.2 E we find that it passes through the two points already found on pp. 213 and 224 (line *AB*, Fig. 74). This line may now be moved to allow for the run of the ship, and may be intersected with another position line to obtain the Fix. (H. O. 201 now discontinued.)

Table H. O. No. 203

The arrangement of this table differs a little from the one just described. The hour angle and the azimuth are given for whole degrees of Lat. and Decl. and Alt. In a column at the right of the hour angle is the difference for one minute of Decl. This makes it easier to interpolate for the odd minutes of Decl. Taking a Lat. of 42°, Decl. −22° 47′ 04″ and altitude of 16° (the nearest to the observed alt.) we find on p. 742 (H. O. No. 203), for Lat. 42°, Decl. contrary name to Lat., the following numbers:

Lat. 42°								
	Decl. 22°				Decl. 23°			
Alt.	Hour Angle	Dif. for 1′ Decl.	Az.	Dif. for 1′ Decl.	Hour Angle	Dif. for 1′ Decl.	Az.	Dif. for 1′ Decl.
15° 00′	$2^h 49^m 16^s$	$7^s.3$	139°.7	.034°	$2^h 41^m 57^s$	$7^s.8$	141°.8	.035°
16 00	2 40 47	7 .7	141 .5	.036	2 33 04	8 .2	143 .6	.037
17 00	2 31 58	8 .2	143 .4	.037	2 23 46	8 .8	145 .6	.039

The hour angle under Decl. 23° and for alt. 16° is $2^h\,33^m\,04^s$. To correct this for Decl. multiply the "Dif. for 1′", $8^s.2$, by 12′.9 and add to the hour angle.

$$\begin{array}{r}
12.9\\
8.2\\
\hline
258\\
1032\\
\hline
105.78 = 1^m\,45^s.8
\end{array}$$

$2^h\,33^m\,04^s + 1^m\,45^s.8 = 2^h\,34^m\,49^s.8$ which corresponds to L. A. T. $9^h\,25^m\,10^s.2$.

To correct the Az. multiply the "Dif. for 1′", 0.037, by 12′.9 and subtract from 143°.6

$$\begin{array}{l}
12.9\\
.037\\
\hline
903\\
387\\
\hline
.4773 = 0^\circ.5
\end{array}$$

$$143^\circ.6 - 0^\circ.5 = 143^\circ.1.$$

The sun's bearing is therefore N 143°.1 E or S 36°.9 E.

To find the longitude to be laid down on the chart we have from p. 234, the Greenwich Apparent Time, $13^h\,07^m\,42^s$. Comparing this with the Loc. App. Time we have the Long.

Gr. App. T.	$13^h\,07^m\,42^s$
Loc. App. T.	$9\quad 25\quad 10\,.2$
Long.	$3^h\,42^m\,31^s.8$
	$= 55^\circ\,38'$ W

Laying down Lat. 42°, Long. 55° 38′ W, drawing a line in direction S 36°.9 E, and laying off 0′.7, the difference between the obs. alt. 16° 00′.7 and the assumed alt. 16° 00′ (toward the sun) we obtain the point *A*, Fig. 78.

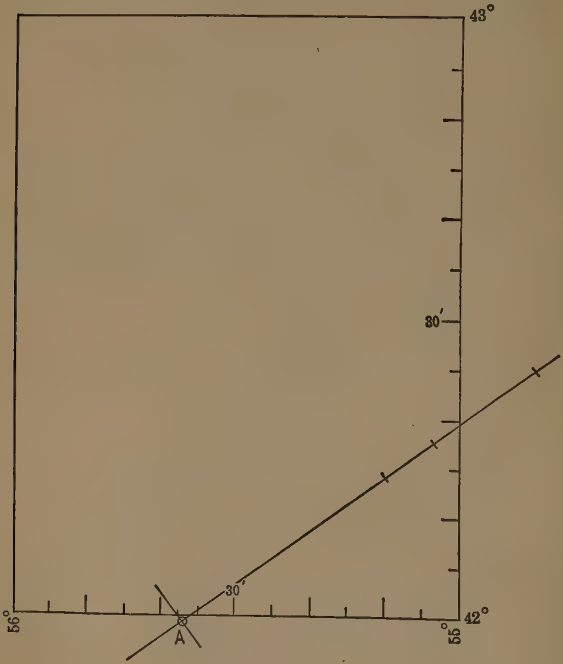


FIG. 78.

Drawing a line in the direction N 53°.1 E we find that it agrees with the line just found by Table No. 201.

USES OF A SINGLE SUMNER LINE

It was stated on p. 202 that when we use Sumner's method we know more about the position of the vessel than we do when we compute a longitude using a D. R. Lat. As an instance of this suppose that we are nearing the land and get a sight which shows that we are on a position line passing through *A*, Fig. 79, and that the bearing of the line is S 40° W (or 220°). This line runs directly into the harbor we are to enter, so we know the course to steer, although we do not know the exact distance. In this case we are safe in following the posi-

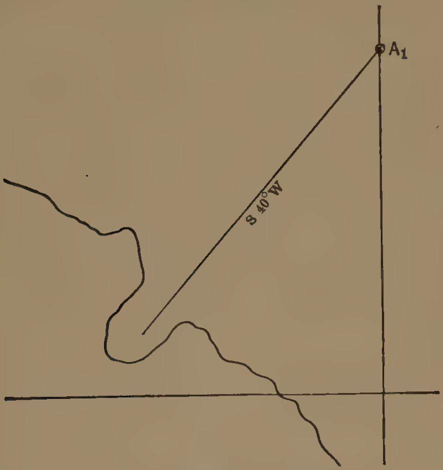


FIG. 79.

tion line. If, on the other hand, the position line runs toward some point of danger then we know the direction of the point we are to avoid, but do not know its distance. A sounding may give a fairly good location on this line. If the position line happens to be about parallel to the coast line then we know our distance off shore, but do not know what point on shore we are opposite. If the bearing of any known object is taken this gives a location on the line.

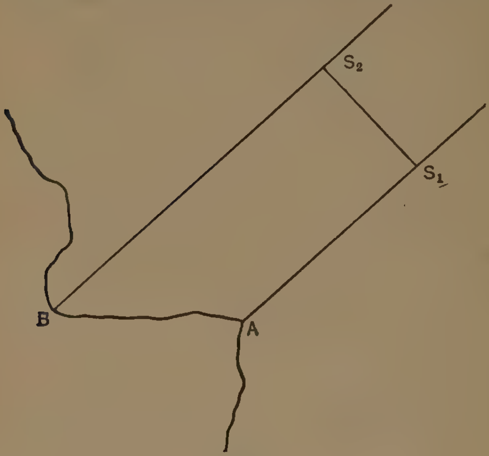


FIG. 80.

Suppose that our position line runs toward a point of danger *A*, Fig. 80, and it is desired to make some other point *B*. We do not know the exact position of the ship, but we may draw a parallel position line passing through

B and then find the distance between the two lines by means of the dividers; if the ship sails from her present position S_1 to point S_2 (at right angles to the position line) she will then be on the line through *B*, and if she follows the line S_2B she will arrive, sooner or later, at *B*, because she is on the right course. The actual distance from S_2 to *B* is not known. It is not necessary to sail from S_1 to S_2; the ship may follow any track that will take her from the line through *A* to some point on the line through *B*, provided it is safe to do so.

The following story, told of a revenue cutter, shows the advantage of understanding the principle of Sumner's method. The cutter picked up a wireless message that a steamer was disabled and needed help. Upon getting into communication the steamer gave her latitude and longitude and the cutter proceeded at once to that position. But no steamer was to be found anywhere near the place stated. The cutter then called the steamer and found that the chronometer had not been compared for a long time and was badly in error. The officer on the cutter then directed the master of the steamer to take an altitude of the sun and to send a signal at the instant of sight, the chronometer on the cutter being read at this same instant. Upon receiving from the master of the steamer this corrected altitude the officer laid down on his chart the position line on which the steamer must be; he then proceeded to a point on that line and followed along the position line until he sighted the steamer some hundred miles from her supposed position.

CORRECTING THE A.M. LONGITUDE AT NOON

When a longitude has been computed in the forenoon, using a D. R. Lat. which is not very reliable, it is not necessary to recompute the longitude when the correct Lat. becomes known, as was frequently done in former years; if it is remembered that the computed position is somewhere on the Sumner line for that altitude all that is necessary is to correct the computed longitude at noon by means of the Long. factor.

Example. Corrected A.M. alt., 56° 00′ 12″; corrected Decl., 21° 43′ 30″ N; D. R. Lat., 44° 00′ N; G. C. T., $14^h\ 28^m\ 26^s$; corrected Equa. of Time, $-5^m\ 36^s$. Working up the sight by the rule on p. 177, we find the longitude to be 66° 51′ W; sun's azimuth, S 59½° E; Long. factor, 0.82. The run to noon is W ¼ N, 11 miles. The Lat. corrected for run is 44° 00′.5 N; the corrected Long. is 67° 06′.3 W. At noon the Lat. as found by observation is 44° 13′ N. This shows that the D. R. Lat. at A.M. sight was 12.5 miles too far south. The Long. factor shows that when the Lat. is increased 1′ the Long. is decreased 0′.82. So when the Lat. is increased 12′.5 the Long. is decreased $12.5 \times 0.82 = 10'.2$ (Fig. 81). Therefore, the noon Long. should have been 66° 56′.1 W.

COMPASS ERROR

Since it is necessary to look up the true bearing, or azimuth, of the sun when laying down a position line we may take this opportunity to find the compass error.

If the compass bearing of the sun is read at the same time as the sun's altitude the compass error may be found at once, because the sun's bearing is the same as that looked up for the purpose of laying down the position line. If the compass bearing is taken a few minutes later than the altitude it is only necessary to allow for the change in bearing during that interval of time.

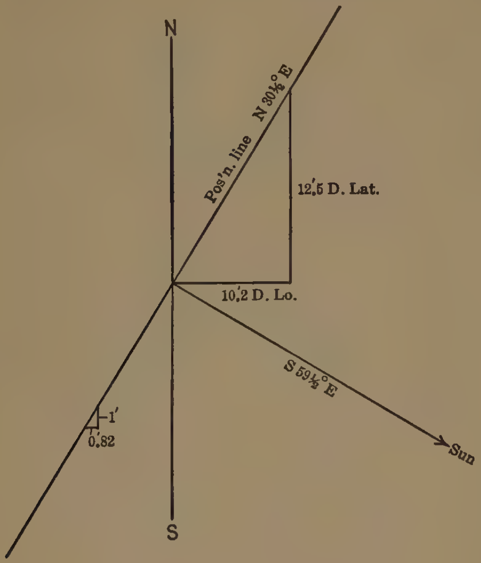


FIG. 81.

Example. The sun's bearing at the time of sight ($9^h\ 55^m\ 26^s$) is S 59½° E. The compass bearing of the sun is taken at $10^h\ 05^m\ 00^s$, and is 148°.5. From the Azimuth Table (71) we see that the bearing decreases 3° 06′ in 10^m of time; the true bearing 10^m later is therefore S 56½° E, or 123½°. This gives a compass error of 25° W.

TABLE H. O. NO. 204.

This table is arranged like No. 203 but the declinations are extended to 63°. It is used for laying down position lines from sights on stars.

H. O. NO. 208.

This set of tables is based on different formulas from the preceding and may be used for lines of position, compass error, meridian altitude, great-circle sailing, and identification of stars. It has the advantage that all of these problems are solved in the same manner and by the same tables.

H. O. 209 AND 211.

Two new tables, 209, Position Tables for Aerial and Surface Navigation, and 211, Dead Reckoning Altitude and Azimuth Tables, have been added to the list.

PROBLEMS

Work the eleven problems on pp. 188–190 by Saint Hilaire's method or by Tables (201 or 203), using latitudes slightly different from those given.

CHAPTER XII

NAVIGATING THE SHIP

Before Leaving Port

In the foregoing pages we have explained the various problems which occur in locating the ship by dead reckoning or by observation. It now remains to show how these would be applied during the day's work of the navigator.

Before leaving port the navigator should measure with a tape from the water surface to places on the vessel at which he expects to make observations, so that he may obtain the height of his eye for the purpose of correcting for dip. He should also note the position of the water line so that allowance may be made for any changes due to change in cargo. He should ascertain the error of his chronometer on Greenwich Civil Time and the rate at which it is gaining or losing. Before leaving he may calculate the chronometer correction for each day of the voyage so that this will not have to be done each time a sight is taken. He should also be provided with a list of compass deviations.

TAKING THE DEPARTURE

One of the most important matters to be attended to before going out of sight of land is to "take the departure." This consists in fixing the position of the vessel from one or more definite land marks of known position. This position of the vessel is really the beginning point of the traverse which is to be kept by dead reckoning. If the vessel passes close to a lighthouse the position as given in the Lighthouse List furnishes a starting point of known Lat. and Long. If the vessel is some distance away from the lighthouse her position may be fixed by a 4-point bearing or any of the methods described in Chapter IV. If two objects are visible the ship may be located by cross bearings. The patent log and the time should be read when this is done and the vessel set on the first course she is to sail for her destination. The position of the point of departure and a note of how it was determined should be entered in the note book.

At the time of taking the departure the ship's clocks, which would naturally be regulated to the time used at the port, should be set to the local apparent time of the meridian of the point of departure.

THE NAVIGATOR'S DAY'S WORK

In navigating by the older methods the least amount of work that would be required each day in the routine of navigating the ship would include (1) working up the dead reckoning for the day's run, including the D. R. position for each sight, the course and distance made good, and the current for the 24 hours; (2) an A.M. sight for longitude and an azimuth to determine the compass error; (3) a noon sight (or an ex-meridian) for latitude; and (4) a P.M. sight for longitude and an azimuth.

In navigating by the newer methods (position lines) it would be necessary to take enough sights to cover the same requirements. The actual number of sights needed and when they should be taken would depend upon the speed of the vessel and upon her location. A high-powered steamer changes her position so rapidly that it is important to get positions more frequently than with a slow steamer or a sailing vessel. A vessel approaching land or navigating in dangerous waters needs a location frequently and it should be an accurate and reliable one. Most of these sights may be worked up by Saint Hilaire's method with or without Tables 201 and 203. It is not necessary to follow the old way of taking the A.M. and P.M. sights when the sun is east or west, or at any fixed time of day. It may be advisable to take one or two star sights early in the morning, or one star sight and a sight on the sun when the sun is high enough for an accurate observation. In this way a Fix is obtained at the beginning of the day. By moving the position lines for run and obtaining new sights the position may be found several times during the day. The noon sight for latitude is so simple and accurate that this should be taken daily, if possible, even though a good Fix has been obtained a short time before.

THE A.M. SIGHT

It has been customary to take a time sight for longitude about 8 A.M. or better still at the time when the sun is east. If this sight is taken there is probably no better way to work it up than by computing the longitude, as explained on p. 177, only, instead of leaving it as a longitude, lay down the position line also; then if there is any error in the D. R. Lat. the line through the true position is known. If no other sight is obtained before noon this longitude may be corrected when the noon latitude is found as explained on p. 244. In winter the sun passes the prime vertical before sunrise. It is necessary to wait until the sun is 10° or so above the horizon before a reliable observation can be made, which at this time of year in high latitudes would be considerably later than 8^h A.M. When the hour angle is about 2^h or 3^h the sight could be worked as a chronometer sight or by Saint Hilaire's method; there would not be much choice in this case; but when the hour angle is less than 2^h Saint Hilaire's method is to be preferred.

In taking the sights some prefer to use a stop watch. The hack chronometer or an observing watch should be compared with the standard chronometers and its correction figured out. The stop watch may be started on some whole minute of the hack or the watch and stopped when the altitude is taken. This gives the seconds at once. If the time is read on the observing watch and the watch is set to local time there will be a large difference between this and Greenwich Time. It is best to compare the chronometer and the watch, calling the difference the "C – W." If the watch is slow of the chronometer the C – W is +; if fast, it is –; that is, if the watch is slow of chronometer we must add the correction to the watch times; if fast, we subtract. The index correction of the sextant should be found each time a sight is taken; it cannot be depended upon to remain the same, day after day. The patent log should be read and recorded when the sight is taken, so that the D. R. position may be found. And it is advisable to take a compass bearing of the sun either at the same time or a few minutes afterward, using the same watch for noting the time. The compass error should be worked out at once and the resulting deviation compared with that in the deviation table. When the next course is set this new deviation should be used. The variation should be looked up on the chart each time the course is set.

The chronometer should be wound daily at some regular time so that it will not be forgotten. Some follow the practice of doing this at the time of the A.M. sight.

THE NOON OBSERVATION

At about 11^h or $11^h\ 30^m$ A.M. the ship's clock should be set to the local apparent time of the meridian where the ship will be at noon. This cannot be done exactly because the run to noon cannot be predicted exactly but it can be done closely enough for practical purposes.

Suppose that the vessel is going west. In this case the watch or clock must be set back by an amount equal to the change in longitude expressed in units of time. The interval of time to noon will really be that much greater than the amount indicated by the Loc. Apparent Time of the A.M. sight. That is, if the sight were taken at $8^h\ 00^m$ A.M. the time to noon would be 4^h if the vessel did not change her longitude; but since she sails west, noon will occur 4^m later for every degree she changes her longitude, and the interval to noon will be that much greater than 4^h.

If the vessel is going east the time of local noon will occur earlier and the changes of longitude must be subtracted to obtain the true interval to noon.

If the speed is very great this longitude difference so found should be corrected for the change in the interval to noon because the run to noon is affected. If the speed is slow this change in the interval to noon may be neglected, if the only object is to find out when the noon sight is to be taken.

Example (from Bowditch). Suppose that the position at A.M. sight is Lat. 38° 03′.2 N; Long. 72° 50′ 26″ W; watch, $8^h\ 00^m\ 03^s.5$; L. A. T., $8^h\ 17^m\ 23^s.9$; course 66°; speed, 11.7 knots. The interval to noon is 12^h less $8^h\ 17^m\ 23^s.9 = 3^h\ 42^m\ 36^s.1$, or $3^h.71$. Entering the traverse tables with the course 66° and speed 11.7 miles, the dep. is 10′.69 which, in Lat. 38°, gives a D. Lo. of 13′.6 per hour; multiplying $3^h.71$ by 13′.6 gives 50′.46 ($= 3^m\ 21^s.8$), the change in longitude to noon. This is the amount by which the watch must be set ahead. Since the watch was already $17^m\ 20^s.4$ slow it must be set ahead $17^m\ 20^s.4 + 3^m\ 21^s.8 = 20^m\ 42^s.2$. This process, however, does not take account of the change of time during the $3^m\ 21^s.8$; but that amounts to only 3^s and has no appreciable effect on the noon observation. If desired it may be taken into account by shortening the run to noon by $3^m\ 21^s.8$ and working out the change in longitude again. The result would be $3^m\ 18^s.6$; therefore the watch must be set ahead $20^m\ 39^s.0$.

The above computation may be made by means of the "Noon Interval Tables," H. O. No. 202. Looking in these tables under the "Local Apparent Time" we find $8^h\ 17^m\ 30^s$ (on p. 43) to be the nearest number given. Looking in the side columns for the change in longitude per hour (eastward) we find for 13′, 3.6555 = $3^h\ 39^m\ 20^s$ and for 14′, 3.6516 = $3^h\ 39^m\ 06^s$. Interpolating to obtain the interval for 13′.6 we find it to be $3^h.6531$ = $3^h\ 39^m\ 11^s.6$. Since the L. A. T. was actually $8^h\ 17^m\ 23^s.9$ instead of $8^h\ 17^m\ 30^s$ this interval would be $6^s.1$ more, or $3^h\ 39^m\ 17^s.7$. This is the "interval to noon." Multiplying the speed, 11′.7, by the interval we obtain 42.7 miles as the run to noon. The watch time of noon would be $8^h\ 00^m\ 03^s.5$ plus $3^h\ 39^m\ 17^s.7$ or $11^h\ 39^m\ 21^s.2$; that is, the watch must be set ahead $20^m\ 38^s.8$ in order to indicate 12^h at the time of local apparent noon.

Now that the watch is set and the noon position approximately known in advance the navigator may compute the "latitude constant" for the meridian altitude of that date and be ready to take his altitude when the watch reads noon.

When the watch reads noon the noon altitude is read and the latitude obtained by subtracting the alt. from the "constant." If there is any doubt about the time then the highest altitude should be observed and this alt. used for finding the Lat. If it is somewhat cloudy just before noon and there is a possibility of losing the noon alt. it is advisable to try to get an alt. 15 to 20 minutes before noon to be worked up as an ex-meridian if the noon alt. is lost.

As soon as the noon Lat. is found the A.M. Long. should be brought up to noon by means of the error in the D. R. Lat. and the longitude factor, as shown on p. 244.

It is recommended by some that the chronometers be wound at noon, instead of at the A.M. sight. At whatever time they are wound it is important to establish a custom and then stick to it so that this matter will not be forgotten.

CURRENT

At noon there will ordinarily be two positions for the ship, one obtained entirely by dead reckoning, the other obtained by observation, and these two will ordinarily be different because the observations are subject to some error and the traverse is subject to a much greater error. It is customary to consider this difference as due to a current which would carry the ship from the D. R. position to the observed position. If the Dif. Lat. and the Dif. Long. turned into Dep. are found in the traverse table, the corresponding course, will be the *set* and the Dist. divided by the number of hours will be the *drift* of the current. The *set* is the direction in which the current moves and the *drift* is the velocity in miles per hour. This discrepancy in positions is really due to wind, bad steering and many other causes as well as to any actual current, but it is customary to call it all *current*.

THE DAY'S RUN

The course and distance "made good" in the 24 hours ending at noon may now be calculated, starting from the point of departure or from the position by observation at the noon of the day before.

Finally the course to be steered for the point of destination and the distance remaining to be run are worked out. (See Chap. V.)

THE P.M. SIGHT

Any sight taken in the afternoon may be worked out in the same manner as the A.M. sight. If the sun is nearly due west the regular time-sight method is the best; for other sights Saint Hilaire's method is usually best. In either case the position line should be plotted. The compass error should be found again either at the time of the P.M. sight or at sunset.

FIXES BY SUMNER LINES

If a vessel is steaming at high speed, or if she is near land, or if for any other reason positions are required frequently then Sumner's method is the best one to use. A Fix from two stars or planets, or from the sun and the moon, taken simultaneously, gives a position which is entirely free from the error of the run. A fix from sights on any two objects with only a few minutes in between sights is practically as good since the run is small.

IDENTIFYING STARS

Sometimes it is necessary to take the altitude of some bright star which can be used for a sight but which cannot be positively identified on account of clouds, too much light, etc. Since we always know the ship's position within a few miles and since we may always take a compass bearing of the star it is possible to identify it from its altitude and azimuth. The tables known as H. O. No. 127 are arranged for this particular purpose. Having corrected the compass bearing of the star for variation and deviation and found the true azimuth, we look up the page marked with the Lat. and then find the azimuth at the top of a column and the altitude at the left hand side of the page. In this column and on this line we find the hour angle and the declination of the star corresponding. To find the right ascension we must first compute the local sidereal time as explained on p. 138. From this sidereal time we subtract the hour angle of the star if west, add if east.

The following example is taken from H. O. No. 127. At sea, Feb. 26, 1925, local civil time 6^h 20^m P.M. Weather overcast and cloudy. Observed the altitude of an unknown star through a break in the clouds to be 31° 30′ (true), bearing 285° (true). What is the name of the star? Ship's position by D. R., Lat. 35° 20′ N, Long. 60° W.

Entering the tables with Lat. 36°, alt. 32°, and az. 76° (nearest values) we find the decl. to be 28°.5 N, hour angle 4^h 38^m W. Converting the local civil time into local sidereal time and subtracting the star's hour angle, we have

Loc. Civ. T. ($18^h\ 20^m$) plus Sid. T. 0^h, G. C. T., ($10^h\ 21^m$) plus 4^m correction for $22^h\ 20^m$ gives $28^h\ 45^m$, or $4^h\ 45^m$ for the Loc. Sid. T. Loc. Sid. T. ($4^h\ 45^m$) minus Star's H. A. ($4^h\ 38^m$) gives $0^h\ 07^m$ for the right ascension. The right ascension is therefore $0^h\ 07^m$ and the declination is 28°.5 N. The star is α *Andromedae* (*Alpheratz*) whose co-ordinates are R. A. $0^h\ 04^m\ 29^s$; Decl. 28° 40′.5 N. There is no other bright star very near α *Andromedae*, so it is not necessary to calculate the R. A. and Decl. more closely.

THE RUDE STAR FINDER AND IDENTIFIER. H. O. 2102.

This device enables the navigator to find by a simple inspection of diagrams (1) the stars and planets visible at twilight or dawn; (2) altitudes and azimuths of stars at a given time; (3) identity of a star whose altitude has been observed; and (4) star azimuths for blotting position lines.

ERRORS IN THE ALTITUDE

No measured altitude is perfect. There will always be some error, owing to refraction, poor horizon, sextant errors, and other causes, and this error may make the altitude too great or too small. Instead of saying that we are on a line of position it would be more accurate to say that we are within a strip of some estimated width. If we suppose that all the errors of altitude may amount to 1′ then our strip is 2′ wide, because we may be out 1′ either way. Any altitude locates us in such a strip. The intersection of two lines of position locates the ship in the area covered by the two. In Fig. 82 this area within which the ship probably lies is *abcd*.

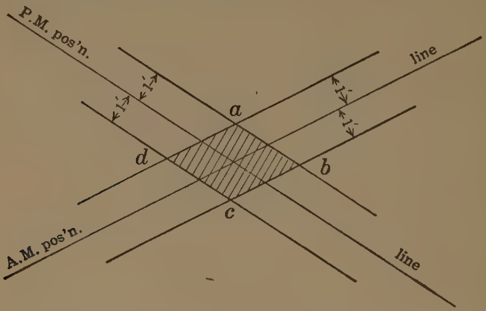


FIG. 82.

If the angle between the two position lines is small (near 0° or 180°) the parallelogram becomes large

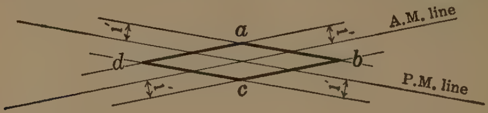


FIG. 83.

(Fig. 83). This shows the importance of choosing sights such that the lines cut nearly at right angles.

ERRORS IN THE GREENWICH TIME

If the chronometer time is uncertain this will produce an error in the longitude no matter how accurate the altitude may be. If it is estimated that the Greenwich

Time may be 8^s out, either way, then we may draw on each side of the position line a parallel which is 2′ (not 2 miles) distant in an east-and-west direction. The ship is then probably within this strip. (Fig. 84.)

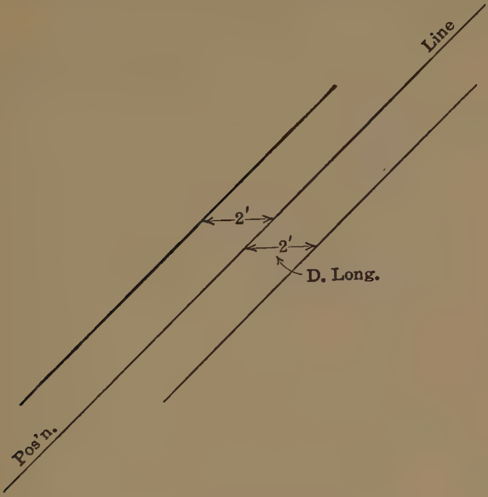


FIG. 84.

THROWING AWAY THE SECONDS

There is always a temptation, when working out a position, to keep the angles in whole minutes and neglect the odd seconds because the work is easier, and, since we frequently find that the position is in error by more than one minute, it would seem to be safe to drop the seconds all the way through the work.

This is not, however, a safe procedure; the seconds will accumulate, and furthermore it sometimes happens that an error of a few seconds in one of the numbers will produce an error of whole minutes in the final result. For example, if we throw away 30″ in the observed altitude, and the same amount in the I. C., the corr. to alt., and the Decl., our Lat. might be in error by 2′ owing wholly to the rejection of seconds, to say nothing of the additional error that might come from poor observing. As another instance, suppose that in winter we are obliged to work out a time sight taken when the sun is rather near the meridian. If the alt. is 25°, the Lat. is 40° N, and the Decl. 20° S, an error due to dropping 30″ in the alt. and 30″ in the Decl. may throw the computed longitude out by nearly 3′. (In such a case it is better to use Saint Hilaire's method.) The only safe rule in all cases is to keep the odd seconds so that the result will be as accurate as possible. Since working to seconds is really too accurate, and working to minutes is not accurate enough, a good plan is to carry all work to tenths of minutes.

THE LOG BOOK

All of the results mentioned above should be entered in the log book. The log should show clearly the following information:

Lat. by obs. at noon
Long. by obs. at noon
Lat. by D. R. at noon
Long. by D. R. at noon
Course and Dist. made good in 24^h
Current in 24^h
Distance run since departure
Course to steer for destination
Distance to run to destination.

It should also contain a record of the meteorological observations taken during the day; a record of the amount of fuel consumed and the amount on hand; and of the events of the day, such as objects sighted, vessels met or passed, etc.

DAY'S WORK ILLUSTRATED

In order to show how some of the preceding methods would be applied in the day's work of the navigator we will suppose that a vessel left Boston at 2^h P.M., Oct. 1, 1917* (Eastern Standard Time), and at $3^h\ 05^m\ 00^s$ P.M. was at Boston Light Ship (42° 20′.4 N, 70° 45′.5 W); chronometer time $20^h\ 06^m\ 30^s$. At the time of leaving port the chronometer was found by comparison to be $1^m\ 29^s$ fast of Greenwich Time and gaining $0^s.5$ daily. The ship's clock was set to local apparent time from the following computation.

---

* The chronometer times for the 1917 observations have been changed to agree with the present system of measuring time.

Chron.	$20^h\ 06^m\ 30^s$
C. C.	$1\ \ 29$
Gr. Civ. T.	$20^h\ 05^m\ 01^s$
Long.	$4\ \ 43\ \ 02$
Loc. Civ. T.	$15^h\ 21^m\ 59^s$
Equa. T.	$+10\ \ 19$
L. A. T.	$15^h\ 32^m\ 18^s$

The clock was therefore $27^m\ 18^s$ slow and was set ahead 27^m making it 18^s slow.

The course to steer for the first turn in the trans-Atlantic track (from Pilot Chart) is found as follows:

Lat. of Turn	43° 00′ N	Long. of Turn	50° 00′ W
Lat. left	42 20 .4 N	Long. left	70 45 .5 W
D. Lat.	39′.6 N	D. Long.	20° 45′.5 E
Mid. Lat.	42° 40′ N		= 1245′.5
		Dep.	= 915′.8 E

from which we find the true course to be 87½°.

The mean variation is 17° W (by Variation chart); deviation (by table) 2° W. The compass course is therefore 106½° (or S 73½° E).

At $7^h\ 10^m\ 30^s$ A.M. (ship's time), having run 309 miles, the alt. $\underline{\odot}$ is taken, 15° 17′ 30″; ht. of eye, 36 ft.; I. C., +1′ 20″; chron. time, $11^h\ 44^m\ 40^s$. The compass bearing of sun at $7^h\ 15^m$ is 131° 30′.

Bringing the D. R. position up to this time we find:

True Course	Dist.	Lat. (N)	Dep. (E)	D. Lo. (E)
87½°	309	13′.6	308′.6	418′.6
				6° 58′.6

Lat. left	42° 20′.4 N	Long. left	70° 45′.5 W
D. Lat.	13 .6 N	D. Long.	6 58 .6 E
Lat. in. (by D. R.)	42° 34′.0 N	Long. in (by D. R.)	63° 46′.9 W

Working out the sight by the "time-sight" method using this D. R. Lat. (Decl. −3° 27′.0; Equa. T. $+10^m\ 31^s$) we find the Long. to be 63° 46′.2 W. The sun's bearing is N 109° 48′ E, from which the Sumner line is laid down on the chart. The Long. factor is 0.50.

For Lat. 42° 34′, Decl. −3° 27′, L. A. T. $7^h\ 43^m\ 06^s$ the sun's azimuth at time of compass bearing is N 110° 37′.

Observed bearing	131° 30′
True bearing	110 37
Compass error	20° 53′ W
Variation	19 W
Deviation	1° 53′ W

The variation is now 19°, so the compass course is changed at 8^h A.M. to 108½° (or S 71½° E).

At 11^h A.M. the clock is set to L. A. T. of the meridian 61° 54′ W, where the ship will probably be at noon. At the time of the morning sight the clock was $28^m\ 10^s$ slow.

The difference between 63° 46′.2 W and 61° 54′ W turned into time is $7^m\ 26^s$, making the clock $35^m\ 36^s$ slow on L. A. T. of the meridian 61° 54′ W.

At noon (Oct. 2) the alt. $\underline{\odot}$ is 43° 37′; ht. of eye, 36 ft.; I. C. +1′ 30″ (Decl. −3° 31′.3). The resulting Lat. is 42° 40′.9 N.

Carrying the A.M. (D. R.) position up to noon by traverse we find:

True Course	Dist.	Lat. (N)	Dep. (E)	D. Lo. (E)
87½°	84	3′.6	83′.9	113′.6

1°53′.6 E

Lat (D. R.)		Long. (D. R.)	
A.M.	42° 34′.0 N	A.M.	63° 46′.9 W
D. Lat.	3 .6 N	D. Lo.	1 53 .6 E
Lat. (D. R.) noon	42° 37′.6 N	Long. (D. R.) noon	61° 53′.3 W

This shows that the position at noon by D. R. is 3′.3 too far south. The A.M. Long. should therefore be corrected by an amount equal to 3′.3 × 0.50 = 1′.7. Since the position line bears NE an increase in Lat. causes a decrease in the longitude.

Calc. Long.	63° 46′.2
Corr.	−1 .7
A.M. Long.	63° 44′.5
Run to noon	1 53 .6
Long. (by ob.) at noon	61° 50′.9

The course and distance made good since leaving point of departure are then worked out.

Lat. of dep.	42° 20′.4 N	Long. of dep.	70° 45′.5 W
Lat. in	42 40 .9 N	Long. in	61 50 .9 W
D. Lat.	20′.5 N	D. Lo.	8° 54′.6 E
			= 534′.6
		Dep.	= 394 .2

Course 87°; Dist. made good, 395 miles, to noon. Average speed, 19.2 knots.

At chronometer time $20^h\ 00^m\ 30^s$ the alt $\underline{\odot}$ was 17° 15′; ht. of eye, 36 ft.; I. C., +1′ 10″; run, 76 miles. (Decl., −3° 35′.1; Equa. T., $+10^m\ 37^s.6$.) At chron. time $20^h\ 05^m$ the compass bearing of sun was 272°. Variation, 22° W.

Running the position up to time of P.M. sight we find:

True Course	Dist.	Lat. (N)	Dep. (E)	D. Lo. (E)
87½°	76	3′.4	75′.9	103′.3

1° 43′.3

Lat. noon	42° 40′.9 N	Long. noon	61° 50′.9 W
D. Lat.	3 .4 N	D. Lo.	1 43 .3 E
Lat. (P.M.)	42° 44′.3 N	Long. (P.M.)	60° 07′.6 W

Working out the time sight with this D. R. Lat., the Long. comes out 60° 09′.9 W. The sun's bearing is N 112° W; Long. factor 0.55. From the compass bearing of the sun the deviation is found to be 1° W.

At chron. time, $23^h\ 01^m\ 20^s$ (Long. 58° 48′ W) the altitude of *Polaris* was 42° 46′; ht. of eye, 36 ft.; I. C.,

+1′ 20″. The Lat. as computed from this observation is 42° 48′.4 N.

PROBLEMS

1. Example of Day's Work. The noon position on July 19, 1917, was Lat. 39° 44′ N, Long. 40° 41′ W. The course was 301°, by compass; variation, 23° W; deviation, 5° W; distance up to time of A.M. sight July 20, 1917, 252 miles. The obs. alt. $\underline{\odot}$ was 31° 01′ 20″; watch time, $7^h\ 39^m\ 27^s$ A.M. C − W,* $+3^h\ 06^m\ 49^s$; C. C., $+08^s$; ht. of eye, 30 ft.; I. C., +10″. Corrected Decl., +20° 44′.6; corrected Equa. T., $-6^m\ 07^s.1$. At watch time $7^h\ 44^m\ 00^s$ A.M. the bearing of the sun by standard compass was 117°, heading 301°. The variation by chart was 22° W. Ship then sailed on course 301°, by compass, 41 miles, var. 22° W, deviation as found above, to noon. At noon the obs. alt. $\underline{\odot}$ was 70° 37′ 40″ bearing south; I. C., +10″; ht. of eye, 30 ft.; chron. time, $15^h\ 08^m\ 00^s$. Corrected Decl. +20° 42′.7; corrected Equa. T., $-6^m\ 07^s.8$.

Find the position at noon by D. R., position at noon by observation, dev. of compass from A.M. sight, course and dist. made good in 24^h, set and drift of current, and course to steer and dist. to Lat. 40° 25′ N. Long. 74° 00′ W.

Ans. The D. R. position at time of A.M. sight is 39° 57′.2 N; Long. 46° 09′.5 W. Working out the time sight, Long. by obs. is 46° 11′ 30″ W, Az. of sun is N 88° 35′ E. Compass error is 28° 25′ W, from which dev. is 6° 25′ W. D. R. position at noon is Lat. 39° 59′.3 N; Long. 47° 02′.9 W. From the obs. at noon we have, Lat. 39° 54′ 39″ N. Bringing the observed Long. up to noon by means of the run we have Long. at noon by obs. 47° 04′.9 W. The course and dist. made good are course 272°, dist. 294 miles. The current has set S 22° W, drift 5.1 miles. Course to steer, 271° 24′; dist. to destination 1244.2 miles.

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* Chronometer time is in Gr. Civ. Time.

2. Example of Day's Work. Noon position Oct. 26, 1917, Lat. 35° 01′ N, Long. 64° 10′ W. Course by compass 128°; var., 13° W; dev., 5° E; run to A.M. sight Oct. 27, 1917, 299 miles. At A.M. sight the alt. $\underline{\odot}$ was 13° 52′, I. C., −20″; ht. of eye, 30 ft.; chron. time,* $11^h\ 21^m\ 50^s$; corrected Decl., −12° 41′.1; corrected Equa. T., $+16^m\ 01^s.1$. On Oct. 1, the chronometer was $1^m\ 20^s$ slow of Gr. Civ. T.; on Sept. 8 it was $1^m\ 01^s$ slow. The run from A.M. sight to noon was 61 miles; course by compass 129°; var., 14° W; dev., 5 E. Meridian alt. $\underline{\odot}$ was 45° 05′ 20″ (bearing south); I. C., −20″; ht. of eye, 30 ft., corrected Decl., −12° 44′.6; corrected Equa. T., $+16^m\ 02^s.1$.

Find the Lat. and Long. at noon Oct. 27; the course and dist. made good since preceding noon; set and drift of current in 24^h; course to steer and dist. to Lat. 10° N, Long. 30° W; var. 15° W, dev., 5° E.

Ans. Noon position by obs., Lat. 32° 00′.5 N, Long. 57° 55′.6 W; course and dist. made good, 120°, 361 miles. Current, 122°, 0′.9 miles. Course to steer; true, 130°; compass 140°. Dist., 2047 miles.

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* Greenwich Civil Time.

CHAPTER XIII

TIDES — STORMS — SIGNALS

Tides

When taking soundings or when navigating in shoal waters the navigator should be able to ascertain the time of high water and to make allowance for the height of the tide. The times and heights of high and low water are given for every day and for all of the principal ports in the Tide Tables issued by the Government. Directions for using these tables are given in the same volume.

If the Tide Tables are not at hand the approximate time of the high tide following the moon's transit may be found by the following rule:

> **Take from the Nautical Almanac the time of upper transit of the moon over the Greenwich meridian, and also the daily variation. Apply to this time of transit the longitude correction given in Table 11, Bowditch, or in Table IV, Nautical Almanac; add the correction in west longitude; subtract in east longitude. Add to this result the high-water lunitidal interval of the port. (Appendix IV, Bowditch.) This gives the local time of High Water. The " establishment of the port " as given on the charts may be used in place of the lunitidal interval.**

Example. Find the time of High Water in the afternoon of March 24, 1925, at Boston, Long. 71° W. The time of transit is $12^h\ 08^m$; hourly var. 49^m.

Time of Transit, Greenwich	$12^h\ 09^m$
Correction for W. Long. 71°	$+10$
Local Time of Transit	$12^h\ 19^m$
Lunitidal interval	$11\ \ 28$
Local Civil Time of H. W.	$23^h\ 47^m$
Reduction of 75° Meridian Time	16
Standard Time	$23^h\ 31^m$
	$= 11^h\ 31^m$ P.M.

If the Greenwich time is desired add the longitude to the local time.

The predicted tides for March 24, 1925, at Boston (Navy Yard) as given in the Tide Tables are as follows, the heavy-faced type indicating P.M. tides:

	h. m.	ft.	h. m.	ft.
24	11 11	10.6	5 02	−1.1
Tu	**11 37**	**10.4**	**5 28**	**−1.3**

The time is Eastern Standard and the heights are above *mean low water*. The predicted time of the P.M. high water is seen to be $11^h\ 37^m$.

ALLOWANCE FOR HEIGHT

In order to make allowance for the variation in the height of the tide a special table is included for this purpose in the Tide Tables. A condensed form of this table is shown on pp. 270 and 271.

To find the amount the water is below the high-water level or the amount it is above the low-water level find from the predicted tides or by observation the "duration"

TABLE 1—HEIGHT OF TIDE AT ANY TIME

Duration of Rise or Fall	TIME FROM THE NEAREST HIGH WATER OR LOW WATER												Duration of Rise or Fall
h. **4**	h.m. 0 10	h.m. 0 20	h.m. 0 30	h.m. 0 40	h.m. 0 50	h.m. 1 00	h.m. 1 10	h.m. 1 20	h.m. 1 30	h.m. 1 40	h.m. 1 50	h.m. 2 00	h. **4**
h. **5**	h.m. 0 12	h.m. 0 25	h.m. 0 38	h.m. 0 50	h.m. 1 02	h.m. 1 15	h.m. 1 28	h.m. 1 40	h.m. 1 52	h.m. 2 05	h.m. 2 18	h.m. 2 30	h. **5**
h. **6**	h.m. 0 15	h.m. 0 30	h.m. 0 45	h.m. 1 00	h.m. 1 15	h.m. 1 30	h.m. 1 45	h.m. 2 00	h.m. 2 15	h.m. 2 30	h.m. 2 45	h.m. 3 00	h. **6**
h. **7**	h.m. 0 18	h.m. 0 35	h.m. 0 52	h.m. 1 10	h.m. 1 28	h.m. 1 45	h.m. 2 02	h.m. 2 20	h.m. 2 38	h.m. 2 55	h.m. 3 12	h.m. 3 30	h. **7**
h. **8**	h.m. 0 20	h.m. 0 40	h.m. 1 00	h.m. 1 20	h.m. 1 40	h.m. 2 00	h.m. 2 20	h.m. 2 40	h.m. 3 00	h.m. 3 20	h.m. 3 40	h.m. 4 00	h. **8**
h. **9**	h.m. 0 22	h.m. 0 45	h.m. 1 08	h.m. 1 30	h.m. 1 52	h.m. 2 15	h.m. 2 38	h.m. 3 00	h.m. 3 22	h.m. 3 45	h.m. 4 08	h.m. 4 30	h. **9**
h. **10**	h.m. 0 25	h.m. 0 50	h.m. 1 15	h.m. 1 40	h.m. 2 05	h.m. 2 30	h.m. 2 55	h.m. 3 20	h.m. 3 45	h.m. 4 10	h.m. 4 35	h.m. 5 00	h. **10**
h. **11**	h.m. 0 28	h.m. 0 55	h.m. 1 22	h.m. 1 50	h.m. 2 18	h.m. 2 45	h.m. 3 12	h.m. 3 40	h.m. 4 08	h.m. 4 35	h.m. 5 02	h.m. 5 30	h. **11**
h. **12**	h.m. 0 30	h.m. 1 00	h.m. 1 30	h.m. 2 00	h.m. 2 30	h.m. 3 00	h.m. 3 30	h.m. 4 00	h.m. 4 30	h.m. 5 00	h.m. 5 30	h.m. 6 00	h. **12**
h. **13**	h.m. 0 32	h.m. 1 05	h.m. 1 38	h.m. 2 10	h.m. 2 42	h.m. 3 15	h.m. 3 48	h.m. 4 20	h.m. 4 52	h.m. 5 25	h.m. 5 58	h.m. 6 30	h. **13**

TABLE I — *Continued*

Range of Tide	Correction to Height												Range of Tide
Ft.	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*
1.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	1.0
2.0	0.0	0.0	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.9	1.0	2.0
3.0	0.0	0.1	0.1	0.2	0.3	0.4	0.6	0.8	0.9	1.1	1.3	1.5	3.0
4.0	0.0	0.1	0.2	0.3	0.4	0.6	0.8	1.0	1.2	1.5	1.7	2.0	4.0
5.0	0.0	0.1	0.2	0.3	0.5	0.7	1.0	1.2	1.5	1.9	2.2	2.5	5.0
6.0	0.0	0.1	0.2	0.4	0.6	0.9	1.2	1.5	1.9	2.2	2.6	3.0	6.0
7.0	0.0	0.1	0.3	0.5	0.7	1.0	1.4	1.8	2.2	2.6	3.0	3.5	7.0
8.0	0.0	0.1	0.3	0.5	0.8	1.2	1.6	2.0	2.5	3.0	3.5	4.0	8.0
9.0	0.0	0.2	0.3	0.6	0.9	1.3	1.8	2.2	2.8	3.3	3.9	4.5	9.0
10.0	0.0	0.2	0.4	0.7	1.0	1.5	2.0	2.5	3.1	3.7	4.3	5.0	10.0
11.0	0.0	0.2	0.4	0.7	1.1	1.6	2.2	2.8	3.4	4.1	4.8	5.5	11.0
12.0	0.1	0.2	0.5	0.8	1.2	1.8	2.3	3.0	3.7	4.4	5.2	6.0	12.0
13.0	0.1	0.2	0.5	0.9	1.3	1.9	2.5	3.2	4.0	4.8	5.7	6.5	13.0
14.0	0.1	0.2	0.5	0.9	1.4	2.1	2.7	3.5	4.3	5.2	6.1	7.0	14.0
15.0	0.1	0.3	0.6	1.0	1.6	2.2	2.9	3.8	4.6	5.6	6.5	7.5	15.0
16.0	0.1	0.3	0.6	1.1	1.7	2.3	3.1	4.0	4.9	5.9	7.0	8.0	16.0
17.0	0.1	0.3	0.6	1.1	1.8	2.5	3.3	4.2	5.2	6.3	7.4	8.5	17.0
18.0	0.1	0.3	0.7	1.2	1.9	2.6	3.5	4.5	5.6	6.7	7.8	9.0	18.0
19.0	0.1	0.3	0.7	1.3	2.0	2.8	3.7	4.8	5.9	7.0	8.3	9.5	19.0
20.0	0.1	0.3	0.8	1.3	2.1	2.9	3.9	5.0	6.2	7.4	8.7	10.0	20.0

of the rise or fall of tide; also find the "range," that is, the difference in height between high and low water. Take the difference between the time of nearest high or low water and the time required. Enter the upper table with the "duration" at the side and on this line find the time from high or low water which is nearest to the actual interval. Then in the same column in the lower table and on line with the "range" is the correction required.

Example. Suppose that a sounding was made at 3^h P.M. Eastern time, March 24, 1925, off Boston and it is desired to reduce this sounding to mean low water. From the Tide Tables the "duration" of the tide between H. W. at $11^h\ 11^m$ A.M. and L. W. at $5^h\ 28^m$ P.M. is $6^h\ 17^m$. The "range" is $10.6 - (-1.3) = 10.6 + 1.3 = 11.9$ ft. The time of the sounding (3^h P.M.) is $2^h\ 28^m$ before L. W. From the upper table on line with 6^h "duration of rise or fall" we find that $2^h\ 30^m$ is the nearest number to $2^h\ 28^m$. In this same column and on line with 12 ft. range we find the correction 4.4 ft. This shows that the water will fall 4.4 ft. before the time of L. W. at $5^h\ 28^m$ P.M. This 4.4 should therefore be subtracted from a sounding made at 3 P.M. to get the depth at mean low water.

This same table may be used to predict the height of water at any time. Suppose that we wish to know the height of water at Boston, March 24, 1925, at 1 P.M. This is $1^h\ 49^m$ after the time of H. W. as given above. Entering the table with "duration" 6^h we find $1^h\ 45^m$, and in the same column in line with 12 ft. the correction is 2.3 ft. The height is therefore 2.3 ft. lower than it is at H. W., that is 10.6 − 2.3 = 8.3 ft. above mean low water. At any place there will be 8.3 ft. more water at 1^h P.M. than is shown on the chart.

CURRENTS

The information about tidal currents is now given in a separate publication, entitled "Current Tables." This Table gives the predicted time of slack water, or when the current turns, for many places along the coast of the United States. It also gives the maximum velocity in knots. In the back of the book are the current diagrams for certain places which may be used to find the velocity at different times and are useful when passing in or out of a harbor.

STORMS.— STORM SIGNALS

For a discussion of the theory of revolving storms see Bowditch, Chapter XIX.

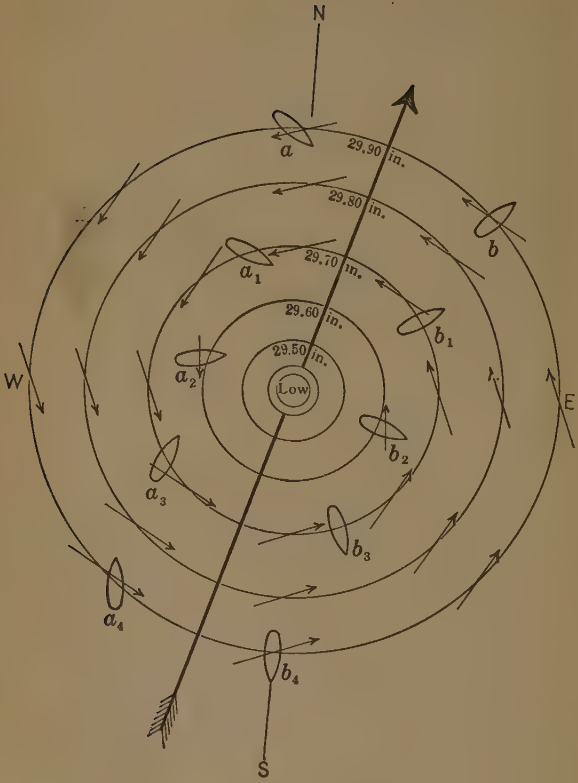
To find the direction of the center of a revolving storm:

Face the wind; then if in North latitude the center is from 8 to 10 points to the right. If in South latitude the center is from 8 to 10 points to the left.

To find which "semicircle" the ship is in:

If the wind shifts toward the right the ship is in the right semicircle (looking along the track of the storm). If the wind shifts toward the left the ship is in the left semicircle.

The diagram on p. 274 represents a cyclonic storm in the Northern Hemisphere after recurving to the north and east, and illustrates the rules as applied to sailing vessels.


N
a
29.90 in.
29.80 in.
b
29.70 in.
a₁
29.60 in.
b₁
29.50 in.
a₂
W
Low
E
b₂
a₃
b₃
a₄
b₄
S

The large arrow shows the direction in which the storm center is moving; the small arrows show the direction of the wind. The barometer readings inside the different circles show the relation between the pressure and the distance of the storm center. The low area is shown as a circle.

The vessel at *a* has the wind about ENE and is in the left, or navigable, semicircle. If she is lying to on the port tack as shown she will turn to the left as shown in positions a_1, a_2, a_3, a_4.

The vessel at *b* has the wind ESE and is in the right, or dangerous, semicircle and lying to on the starboard tack. As the storm advances she turns to the right as shown in the positions b_1, b_2, b_3, b_4.

RULES FOR MANEUVERING A VESSEL IN THE PRESENCE OF CYCLONIC STORMS

[Pilot Chart, Hydrographic Office.]

NORTHERN HEMISPHERE

Right or dangerous semicircle. — Steamers: Bring the wind on the starboard bow, make as much way as possible, and if obliged to heave to, do so head to sea. Sailing vessels: Keep close hauled on the starboard tack, make as much way as possible, and if obliged to heave to, do so on the starboard tack.

Left or navigable semicircle. — Steam and sailing vessels: Bring the wind on the starboard quarter, note the course and hold it. If obliged to heave to, steamers may do so stern to sea; sailing vessels on the port tack.

On the storm track, in front of center. — Steam and sailing vessels: Run for the left semicircle with wind on starboard quarter, and when in that semicircle maneuver as above.

On the storm track, in rear of center. — Avoid it by the best practicable route, having due regard for the storm's recurving to the northward and eastward.

SOUTHERN HEMISPHERE

Left or dangerous semicircle. — Steamers: Bring the wind on the port bow, make as much way as possible, and if obliged to heave to, do so head to sea. Sailing vessels: Keep close hauled on the port tack, make as much way as possible, and if obliged to heave to, do so on the port tack.

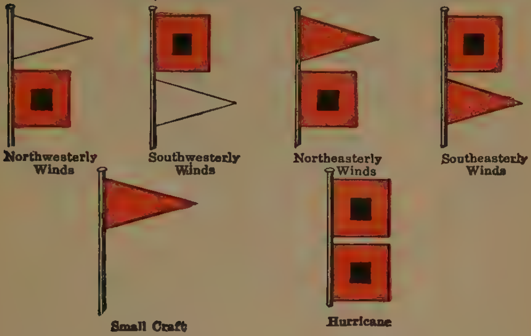
Right or navigable semicircle. — Steam and sailing vessels: Bring the wind on the port quarter, note the course and hold it. If obliged to heave to, steamers may do so stern to sea; sailing vessels on the starboard tack.

On the storm track, in front of center. — Steam and sailing vessels: Run for right semicircle, with wind on port quarter, and when in that semicircle maneuver as above.

On the storm track, in rear of center. — Avoid it by the best practicable route, having due regard for the storm's recurving to the southward and eastward.

The above rules depend, of course, upon having sea room. In case land interferes, a vessel should heave to, as recommended for the semicircle in which she finds herself.

SMALL CRAFT, STORM AND HURRICANE WARNINGS.



Small craft warning. — A red pennant indicates that moderately strong winds are expected.

Storm warning. — A red flag with a black center indicates that a storm of marked violence is expected.

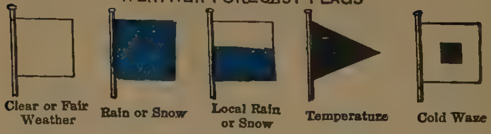
The pennants displayed with the flags indicate the direction of the wind: White, westerly; red, easterly. The pennant above the flag indicates that the wind is expected to blow from the northerly quadrants; below, from the southerly quadrants.

By night a red light indicates easterly winds, and a white light below a red light, westerly winds.

Hurricane warning. — Two red flags with black centers displayed one above the other, indicate the expected approach of a tropical hurricane, or one of those extremely severe and dangerous storms which occasionally move across the Lakes and northern Atlantic coast.

Small craft or hurricane warnings are not displayed at night.

WEATHER FORECAST FLAGS



Number 1, white flag, indicates clear or fair weather. Number 2, blue flag, indicates rain or snow. Number 3, white and blue flag (parallel bars of white and blue), indicates that local rains or showers will occur, and that the rainfall will not be general. Number 4, black triangular flag, always refers to temperature; when placed above numbers 1, 2, or 3, it indicates warmer weather; when placed below numbers 1, 2, or 3 it indicates colder weather; when not displayed, the indications are that the temperature will remain stationary, or that the change in temperature will be slight. Number 5, white flag, with black square in center, indicates the approach of a *sudden* and *decided* fall in temperature, and is displayed alone.

When displayed on poles the flags should be arranged to read downward; when displayed from horizontal supports a small streamer should be attached to indicate the point from which the flags are to be read.

Signals — Lights — Rules of the Road

WHISTLE SIGNALS

The whistle signals for steam vessels are:

One short blast (one second), meaning, "I am directing my course to starboard."

Two short blasts, meaning, "I am directing my course to port."

Three short blasts, meaning, "My engines are going full speed astern."

Four or more short blasts, meaning, "You are standing into danger."

RULE I. If, when steam vessels are approaching each other, either vessel fails to understand the course or intention of the other, from any cause, the vessel so in doubt shall immediately signify the same by giving several short and rapid blasts, not less than four, of the steam whistle, the DANGER SIGNAL.

RULE II. Steam vessels are forbidden to use what has become technically known among pilots as "CROSS SIGNALS," that is, answering one whistle with two, and answering two whistles with one.

RULE III. The SIGNALS FOR PASSING, by the blowing of the whistle, shall be given and answered by pilots, in compliance with these rules, not only when meeting "head and head," or nearly so, but at all times, when the steam vessels are in sight of each other, when passing or meeting at a distance within half a mile of each other, and whether passing to the starboard or port.

The whistle signals provided in the rules for steam vessels meeting, passing, or overtaking, are never to be used except when steam vessels are in sight of each other, and the course and position of each can be determined in the daytime by a sight of the vessel itself, or by night by seeing its signal lights. In fog, mist, falling snow or heavy rainstorms, when vessels can not so see each other, fog signals only must be given.

The following condensed statements cover some of the more important cases.

When steam vessels are approaching each other head and head, or nearly so, it shall be the duty of each to pass on the port side of the other.

When a steam vessel is nearing a short bend or curve in the channel, which is obscured by high banks, such steam vessel shall give a signal by one long blast of the whistle.

When steam vessels are moved from their docks they shall give one long blast, 4 to 6 seconds, but after clearing the berth so as to be in sight they shall be governed by the steering and sailing rules.

When steam vessels are running in the same direction and the vessel which is astern shall desire to pass on the right of the vessel ahead she shall give one short blast of the whistle. If the vessel ahead answers with one blast she shall then put her helm to port. If she shall desire to pass on the left she shall give two short blasts of the whistle, and if the vessel ahead answers with two blasts she shall put her helm to starboard. If the vessel ahead does not think it safe to pass at that point she shall give 4 or more short blasts of the whistle.

When two steam vessels are approaching each other at right angles or obliquely the steam vessel which has the other on her own starboard side shall keep out of the way of the other vessel.

When a steam vessel and a sailing vessel are approaching, the steam vessel shall keep out of the way of the sailing vessel.

A steam vessel which is directed by the rules to keep out of the way of another vessel shall avoid crossing ahead of the other.

In narrow channels every steam vessel shall keep to that side of the channel which lies on the starboard side of such vessel.

In fog a steam vessel under way shall sound a prolonged blast at intervals of not more than one minute. A steam vessel towing other vessels shall sound one long and two short blasts. A vessel at anchor shall ring the bell rapidly for 5 seconds at intervals of not more than one minute.

SAILING VESSELS

When two sailing vessels are approaching:

(a) A vessel which is running free shall keep out of the way of a vessel which is close hauled.

(b) A vessel close hauled on the port tack shall keep out of the way of a vessel close hauled on the starboard tack.

(c) When both are running free, with the wind on different sides, the vessel which has the wind on the port side shall keep out of the way of the other.

(d) When both are running free, with the wind on the same side, the vessel which is to the windward shall keep out of the way of the vessel which is to the leeward.

(e) A vessel which has the wind aft shall keep out of the way of the other vessel.

LIGHTS

A steam vessel under way is obliged to carry a green light on the starboard side and a red light on the port side, visible everywhere from right ahead to two points abaft the beam. She also carries a white light at the masthead, not less than 20 feet above the hull, and visible at a distance of at least 5 miles. She may carry an additional white light, the two to be in line with the keel, their difference in height to be at least 15 feet, and the lower light to be forward of the upper one.

A steam vessel towing another vessel carries also two bright white lights, in a vertical line, and not less than 6 feet apart.

A vessel which, owing to accident, is not under command must carry two red lights at the height of, and in place of, her white masthead light. These lights must be in a vertical line and at least 6 feet apart.

Pilot vessels, when on duty, do not show the lights required for other vessels, but carry a white light at the masthead and show a flare-up light every 15 minutes. A steam pilot vessel, on duty, carries also a red light 8 feet below her masthead light.

A sailing vessel under way and a vessel being towed shall carry the red and green lights required for steamers, but shall not carry the white lights.

A vessel at anchor does not carry the red and green lights but shows one or two white lights according to her length.

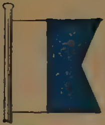
A complete statement of the laws and rules concerning lights, signals, etc., is given in "Pilot Rules, etc.," issued by the Department of Commerce, Steamboat Inspection Service, and in Circular No. 230, Dept. of Commerce, Bureau of Navigation.

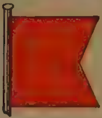
INTERNATIONAL SIGNAL CODE

The International Code of Signals consists of 26 flags, one for each letter of the alphabet, and the code flag or answering pennant (pp. 284–5). Two of these (A, B) are burgees, five (C to G) are pennants and the rest are square flags. The Code Book is published by the Navy Department and contains full instructions for making and answering all signals. The International Code is printed in all languages, so that vessels may communicate without either one understanding the written language of the other.

Each code flag has a certain meaning when hoisted singly or with the code pennant. Urgent signals are made with two flags. Two-flag signals with the code pennant at the top are for latitude and longitude. Three-flag signals are usually compass (magnetic) or general vocabulary signals. Four-flag hoists are geographical or alphabetical signals.

To open communication by the Code, show the ensign with the code pennant under it. This should be answered by hoisting the answering pennant (code pennant


A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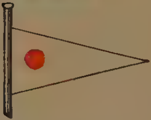
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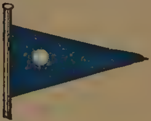
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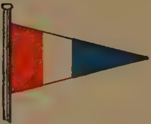
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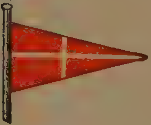
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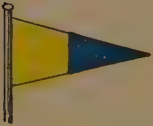
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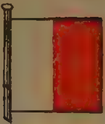
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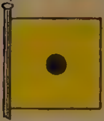
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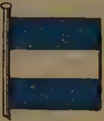
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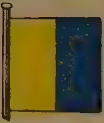
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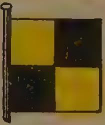
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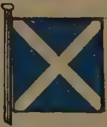
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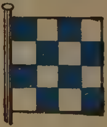
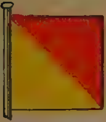

N

[illegible]

O


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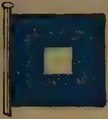

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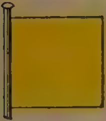

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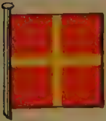

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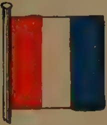
T


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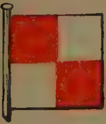

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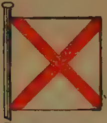

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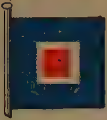
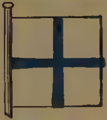


X


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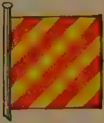

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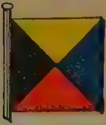
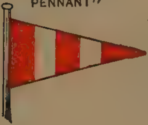


"CODE FLAG" AND
"ANSWERING
PENNANT"



When used as the Code
Flag it is to be hoisted
under the Ensign.
When used as the
Answering Pennant
it is to be hoisted at
the mast head or where
best seen.

by itself). When the signal itself is hoisted the code flag is hauled down. Each hoist should be answered by the answering pennant. When a ship has finished signaling she hauls down her ensign.

Communication may be commenced, and any messages following, or found under the heading "Danger or Distress" in the International Code Signal Book, may be exchanged, strictly following the International Commercial Code and the instructions given below.

The above signal, asking to open communication, should be shown in every case of distress by the shore station, for it may be that the vessel has the International Code, but, until seeing this signal, will not know that she can use it.

Signals Adopted from and to be Found in International Commercial Code Signal Book

NC	In distress; want immediate assistance	FR	Bar is impassable
DC	We are coming to your assistance.	IED	Cast off
EY	Do not attempt to land in your own boats.	RIF	Make fast to ——
BI	Damaged rudder; cannot steer.	WFQ	Slack away
BJ	Engines broken down; I am disabled.	KT	Shift your berth. Your berth is not safe.
JD	You are standing into danger	KP	Hold on until high water.
FZ	Heavy weather coming; look sharp.	KH	Remain by the ship.
AB	Abandon the vessel as fast as possible.	YF	Want assistance; mutiny.
KD	Landing is impossible.	YL	Want immediate medical assistance.
KF	Look out for rocket line (*or*, line).	YG	Want a boat immediately (*if more than one, number to follow*).

KA	Endeavor to send a line by boat (cask, kite, raft, etc.).	YP	Want a tug (*if more than one, number to follow*).
CX	No assistance can be rendered; do the best you can for yourselves.	AG	I must abandon the vessel.
KG	Lookout will be kept on the beach all night.	PT	Want a pilot.
KE	Lights, or fires will be kept at the best place for coming on shore.	VG	What is name of ship or signal station in sight?
KC	Keep a light burning.	DU	Repeat ship's name; your flags were not made out.
AD	Do not abandon the vessel until the tide has ebbed.	WCX	Signal not understood; though the flags are distinguished.
NM	I am on fire.	NCX	I cannot make out the flags (*or*, signals).
NO	I am sinking (*or*, on fire); send all available boats to save passengers and crew.	C	Assent — yes.
		D	Negative — no.

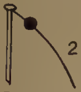
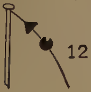
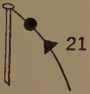
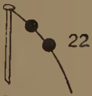
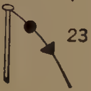
SPECIAL DISTANT SIGNALS

The following distant signals may be used when. on account of distance, the code flags cannot be distinguished.

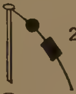
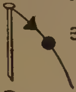
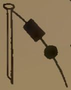
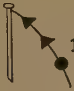
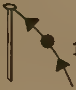
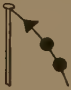
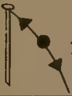
SPECIAL DISTANT SIGNALS

Made by a single hoist followed by the STOP signal. Arranged numerically for reading off a signal.

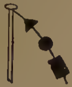
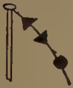
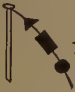
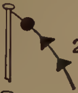
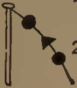
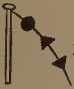
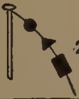
These Signals may be made by the Semaphore, by Cones, Balls, and Drums, or by Square Flags, Balls, Pennants, and Whefts.

SIGNAL.	MEANING
 2	"Preparative," "Answering," *or*, "Stop," after each complete signal.
 12	Aground; want immediate assistance.
 21	Fire, *or* Leak; want immediate assistance.
 22	Annul the whole signal.
 23	You are running into danger, *or* Your course is dangerous.

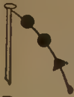
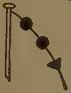
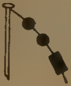
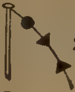
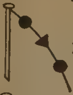
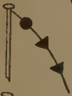
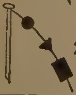
Special distant signals, arranged numerically

SIGNAL	MEANING
 24	Want water immediately.
 32	Short of provisions; starving.
 42	Annul the last hoist; I will repeat it.
 112	I am on fire.
 121	I am aground.
 122	Yes, *or*, affirmative.
 123	No, *or*, Negative

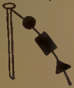
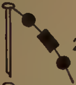
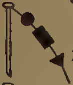
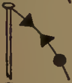
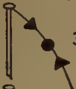
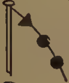
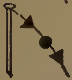
Special distant signals, arranged numerically

Signal	Meaning
 124	Send lifeboat.
 132	Do not abandon the vessel.
 142	Do not abandon the vessel until the tide has ebbed.
 211	Assistance is coming.
 212	Landing is impossible.
 213	Bar, *or*, Entrance is dangerous.
 214	Ship disabled; will you assist me into port?

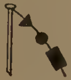
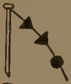
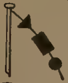
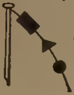
Special distant signals, arranged numerically

Signal	Meaning
 221	Want a pilot.
 223	Want a tug; can I obtain one?
 224	Asks the name of ship (*or*, signal station) in sight, *or*, Show your distinguishing signal.
 231	Show your ensign.
 232	Have you any dispatches (message, orders, *or*, telegrams) for me?
 233	Stop, Bring-to, *or*, Come nearer; I have something important to communicate.
 234	Repeat signal, or hoist it in a more conspicuous position.

Special distant signals, arranged numerically

Signal	Meaning
 241	Can not distinguish your flags; come nearer, or make Distant Signals.
 242	Weigh, Cut, *or*, Slip; wait for nothing; get an offing.
 243	Cyclone, Hurricane, *or*, Typhoon expected.
 312	Is war declared? *or*, Has war commenced?
 321	War is declared, *or*, War has commenced.
 322	Beware of torpedoes; channel is mined.
 323	Beware of torpedo boats.

Special distant signals, arranged numerically

Signal	Meaning
 324	Enemy is in sight.
 332	Enemy is closing with you, *or*, You are closing with the enemy.
 342	Keep a good look-out, as it is reported that enemy's men-of-war are going about disguised as merchantmen.
 412	Proceed on your voyage.

DISTRESS SIGNALS

(SEE ARTICLE 31 OF INTERNATIONAL RULES.)

When a vessel is in distress and requires assistance from other vessels or from the shore the following shall be the signals to be used or displayed by her, either together or separately, namely:

In the daytime —

(1) A gun or other explosive signal fired at intervals of about a minute.

(2) The International Code signal of distress indicated by NC.

(3) The distant signal, consisting of a square flag,

aving either above or below it a ball or anything esembling a ball.

(4) A continuous sounding with any fog-signal ap-aratus.

At night —

(1) A gun or other explosive signal fired at intervals f about a minute.

(2) Flames on the vessel (as from a burning tar barrel, oil barrel, and so forth).

(3) Rockets or shells throwing stars of any color or escription, fired one at a time, at short intervals.

(4) A continuous sounding with any fog-signal apparatus.

FORMULAS

No formulas have been introduced into the text because it was assumed that those using the book may not be accustomed to algebraic notation. Those who prefer the formulas will find in the following table all of the important formulas which have been used in the book.

Plane Sailing

Known	Find	Formulas
Course (C) and Distance	D. Lat. and Dep.	log D. Lat. = log Dist. + log cos C log Dep. = log Dist. + log sin C
D. Lat. and Dep.	Course and Dist.	log tan C = log Dep. − log D. Lat. log Dist. = log Dep. − log sin C

PARALLEL SAILING

Known	Find.	Formulas
Dep. and Lat.	D. Lo.	log D. Lo. = log Dep. + log sec Lat.
Lat and D. Lo.	Dep.	log Dep. = log D. Lo. + log cos Lat.

MIDDLE LATITUDE SAILING

Both Lats. and Longs.	Dep., Course and Dist.	log Dep. = log D. Lo. + log cos mid. Lat. log tan C = log Dep. − log D. Lat. log Dist. = Dep. + log csc C
D. Lat., Dep. and mid. Lat.	Course, Dist. and D. Lo.	log tan C = log Dep. − log D. Lat. log Dist. = log Dep. + log csc C log D. Lo. = log Dep. + log sec mid. Lat.
Lat. left, Course and Dist.	D. Lat., Dep. and D. Lo.	log D. Lat. = log Dist. + log cos C log Dep. = log Dist. + log sin C log D. Lo. = log Dep.+log sec. mid. Lat.

MERCATOR SAILING

Both Lats. and Longs.	Course, Dist. and Dep.	log tan C = log D. Lo. − log m. log Dist. = log D. Lat. + log sec C log Dep. = log Dist. + log sin C.
Lat. and Long. left, Course and Dist.	D. Lat., D. Lo.	log D. Lat. = log Dist. + log cos C log Dep. = log Dist. + log sin C log D. Lo. = log m + log tan C

GREAT-CIRCLE SAILING

$$\text{hav. Dist.} = \text{hav.}\,(\text{Lat.}_A \sim \text{Lat.}_B) + \cos \text{Lat.}_A \cos \text{Lat.}_B \,\text{hav. D. Lo.}$$

$$\sin C_A = \sin \text{D. Lo.} \cos \text{Lat.}_B \,\text{cosec Dist.}$$

$$\sin C_B = \sin \text{D. Lo.} \cos \text{Lat.}_A \,\text{cosec Dist.}$$

or

$$\tan \theta = \cos \text{D. Lo.} \cot \text{Lat.}_B$$

$$\cot C_A = \cot \text{D. Lo.} \cos (\text{Lat.}_A + \theta) \,\text{cosec}\, \theta$$

$$\cot \text{Dist.} = \cos C_A \tan (\text{Lat.}_A + \theta)$$

FOR THE VERTEX

$$\cos \text{Lat.}_V = \sin C_A \cos \text{Lat.}_A$$

$$\cot \text{D. Lo.}_{AV} = \tan C_A \sin \text{Lat.}_A$$

$$\tan \text{Dist.}_{AV} = \cos C_A \cot \text{Lat.}_A$$

Latitude

MERIDIAN ALTITUDE

$$\text{Lat.} = 90^\circ - \text{Alt.} + \text{Decl.}$$

EX-MERIDIAN ALTITUDE

$$\text{Lat.} = 90^\circ - (\text{Alt.} + at^2) + \text{Decl.}$$

Longitude

TIME SIGHT

$$s = \tfrac{1}{2}\,(\text{Alt.} + \text{Lat.} + \text{pol. dist.})$$

$$\log \text{hav.}\, t = \log \sec \text{Lat.} + \log \text{cosec pol. dist.} + \log \cos s + \log \sin (s - \text{alt.})$$

Azimuth

$$\log\cos\tfrac{1}{2}\,\text{Az.} = \tfrac{1}{2}\,[\log\cos s + \log\cos(s - \text{pol. dist.}) + \log\sec\text{Lat.} + \log\sec\text{alt.}]$$

$$\log\sin\text{Az.} = \log\sin t + \log\cos\text{Decl.} + \log\sec\text{alt.}$$

Amplitude

$$\log\sin\text{Ampl.} = \log\sec.\,\text{Lat.} + \log\sin\text{Decl.}$$

Altitude (SAINT HILAIRE)

$$\log\text{hav.}\,\theta = \log\cos\text{Lat.} + \log\cos\text{Decl.} + \log\text{hav.}\,t$$

$$\text{nat. hav. Z. D.} = \text{nat. hav.}\,\theta + \text{nat. hav. (Lat.} \sim \text{Decl.)}$$

$$\text{Alt.} = 90^\circ - \text{Z. D.}$$

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